

# EMISSIONS PERFORMANCE OF AN 85-KILOWATT PACKAGED COMBINED HEAT AND POWER SYSTEM

*Prepared For:*  
**California Energy Commission**  
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*Prepared By:*  
Electric Power Research Institute  
**EPRI**



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PIER FINAL PROJECT REPORT

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## Preface

The California Energy Commission's Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grants
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

*Emissions Performance of an 85-Kilowatt Packaged CHP System* project (Contract Number 500-02-014, Work Authorization Number 131) conducted by Electric Power Research Institute (EPRI). The information from this project contributes to PIER's Environmentally Preferred Advanced Generation Program.

For more information about the PIER Program, please visit the Energy Commission's website at [www.energy.ca.gov/research/](http://www.energy.ca.gov/research/) or contact the Energy Commission at 916-654-4878.



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## Abstract

This project evaluated the capability of an 85-kilowatt electric commercial-packaged combined-heat-and-power unit (Model ENI-85), designed and manufactured by I Power Energy Systems Limited Liability Company (I Power), to meet the California Air Resources Board 2007 emissions guidelines for distributed generators. This packaged combined-heat-and-power (CHP) unit is powered by an 8.1 liter, eight-cylinder internal combustion engine manufactured by General Motors and modified by I Power for clean natural gas combustion.

The Model ENI-85 was tested using a test plan consistent with the Association of State Energy Research and Technology Transfer Institutions field test protocols and California Air Resources Board emissions measurement protocols.

The measured heat rate of the Model ENI-85 was about 5 percent higher than I Power specified for the Model ENI-85. The measured overall electrical and thermal recovery was about 78.9 percent as compared to an 85 percent fuel utilization efficiency advertised by I Power. Measured electrical capacity of the Model ENI-85 was as advertised, approximately 85.5 kilowatts, net. Measured emissions satisfied the California Air Resources Board 2007 emissions requirement of 0.07 pounds/megawatt-hour for nitrogen oxides and 0.1 pounds/megawatt-hour for carbon monoxide.

**Keywords:** Internal combustion engine, natural gas-fired CHP, distributed generation, combined heat and power, I Power Energy Systems LLC



## Executive Summary

The widescale deployment of combined-heat-and-power (CHP) units in California is limited due to the lack of availability of CHP units capable of meeting the California Air Resources Board 2007 emissions guidelines for distributed generators<sup>1</sup>. As of mid-2007, no internal combustion engine-based combined-heat-and-power unit had been shown to meet the California Air Resources Board 2007 emissions standards for distributed generators.

A packaged combined-heat-and-power unit (Model ENI-85), available from I Power Energy Systems Limited Liability Company (I Power), uses an 8.1 liter, eight-cylinders internal combustion engine manufactured by General Motors and modified by I Power to improve durability and reduce emissions.

The net operating benefits of combined-heat-and-power units (electrical output plus thermal output, less fuel purchased and less operations and maintenance costs) typically require maximum use of the thermal output. For applications where the thermal output can be less than the thermal capacity of the combined-heat-and-power unit, the unit electrical output must be modulated to match the site thermal load. The ENI-85 unit tested here was delivered with electrical dispatch capabilities only. Thermal dispatch capability of the unit is not offered by I-Power. The unit controls were modified on-site to allow investigation of thermal dispatch performance.

The Model ENI-85 unit was tested at Southern California Gas Company's (SoCalGas) Engineering Analysis Center in Pico Rivera. The installation included a grid connection in parallel with an electric load on-site and a thermal radiator to serve as a thermal load on-site, and associated monitoring and data logging instruments.

The unit's primary cooling loop absorbs heat in the engine water jacket, and an exhaust-to-coolant heat exchanger and delivers heat to a secondary cooling loop through a liquid-to-liquid heat exchanger. Secondary loop heat can be delivered at a temperature of approximately 160° Fahrenheit for further use.

The test plan prepared for testing I Power's Model ENI-85 was consistent with the Association of State Energy Research and Technology Transfer Institutions field test protocols and California Air Resources Board emissions measurement protocols. It included a series of steady-state baseline energy and emissions performance tests designed to evaluate this combined-heat-and-power technology as well as longer-term thermal load-following tests.

The measured I Power ENI-85 heat rate was about 5 percent higher than the manufacturer's heat rate specifications. The measured overall electrical and thermal recovery was about 78.9 percent as compared to an 85 percent fuel utilization efficiency advertised by I Power. Measured electrical capacity of the ENI-85 was as advertised, approximately 85.5 kilowatts net.

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*1 Final Regulatory Order Amendments to the Distributed Generation Certification Regulation, California Environmental Protection Agency, Air Resources Board, Stationary Source Division, Project Assessment Branch. August 2007. <http://www.arb.ca.gov/regact/dg06/dg06.htm>.*

In general, the ENI-85 unit is a well built and reliable unit. It operated smoothly once all the set-points and initial configuration settings were programmed. The most significant issues for operation were:

- The engine controls were very sensitive. The manufacturer's representative required two visits over several days to tune the unit to the exacting California Air Resources Board 2007 emissions requirements. The engine controls tend to overreact to slight variations in load. While the average emission levels were maintained, spikes in emission levels occurred randomly and sporadically during operation.
- The ENI-85 power output controls were unstable in the thermal load following mode (an application for which it is not presently marketed). The unit seemed unable to stabilize the return water temperature to the engine. Several changes were made to the process control proportional-integral-derivative, which slightly improved the unit response to the change in the return water temperature, but further controls development will be required to produce an acceptable combined-heat-and-power system capable of performing under varying thermal and electrical load conditions.

The ENI-85 unit can operate within the California Air Resources Board 2007 emissions guidelines if there is an assured thermal load greater than the rated electrical output of the ENI-85. In other applications, it will require continuous monitoring and frequent adjustments of the unit output controls.

Widescale deployment of clean and efficient CHP units, such as Model ENI-85, in California would benefit California CHP customers by reducing their energy costs while reducing pollution and preserving the environment.

## 1.0 Introduction

When heat cogenerated with electrical power is used to reduce fuel consumption (that would be otherwise necessary to meet a local heat load), the fuel use efficiency is maximized and the overall fuel use is reduced. In most cases, the net operating benefits (electrical output plus thermal output less fuel and operations and maintenance [O&M] costs) will be positive, allowing recovery of capital and installation costs.

While a favorable cost/benefit analysis will be critical to widespread implementation of combined-heat-and-power (CHP) units, the ability to achieve acceptably low emissions will be a necessary condition. The California Air Resources Board (ARB) has published emissions guidelines for distributed generators, including CHP units<sup>2</sup>. As of mid-2007, no internal combustion engine (ICE)-based CHP plants qualified to meet these guidelines. Internal combustion engines are the most mature (and lowest cost) power generation technology for CHP applications. The availability of an ICE-based CHP power unit that meets the ARB 2007 guidelines would be a significant step to wide-spread use of CHP in California.

### 1.1. Project Purpose

The I Power Energy Systems ENI-85 is one of several promising CHP technologies in commercial production. The ENI-85 is a fully packaged, continuous duty, internal combustion engine, generator, and thermal recovery unit. This packaged CHP unit is powered by an 8.1 Liter (L) V-8 internal combustion engine manufactured by GM and modified by I Power for near-stoichiometric, clean natural gas combustion. The modifications include durability-related changes such as proprietary valve train components, materials, and actuation, and precision metering of head lubrication. The modifications also include provisions to reduce package emissions including an integrated engine throttle and governor, closed-loop fuel control, active ignition control and a proprietary three-way exhaust catalyst configuration.

The purpose of the work reported here is to quantify the operational characteristics of I Power Energy Systems ENI-85 packaged CHP generator set with low emissions controls. The model and serial numbers for the unit under test were ENI-85 and 0612-121, respectively. This unit was leased for testing at the Southern California Gas Company (SoCalGas) Power Quality and Distributed Energy Resources Test Laboratory located at the Engineering and Analysis Center (EAC) in Pico Rivera, CA. The testing included a series of steady-state baseline energy and emissions performance tests designed to evaluate this distributed energy resources (DER) technology, as well as a preliminary look at the thermal load-following capabilities of the unit.

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<sup>2</sup> *Final Regulatory Order Amendments to the Distributed Generation Certification Regulation*, California Environmental Protection Agency, Air Resources Board, Stationary Source Division, Project Assessment Branch. August 2007. <http://www.arb.ca.gov/regact/dg06/dg06.htm>.

## 1.2. Organization and Responsibilities

The work responsibilities for this test project are shown below:

- Unit Installation and Operation – The EAC team installed and operated the unit, the instrumentation and other equipment used for the project.
- Commissioning and Start-Up – I Power conducted the commissioning and start-up in coordination with the EAC.
- Data Acquisition – The EAC collected operating data and analyzed the system performance.
- Reporting – A Test Data Report was prepared by the EAC team and provided to project participants for review and comments before being finalized.
- This final project report was prepared for Electric Power Research Institute by Professional Energy Solution, Inc.

## 1.3. Relationship to PIER Goals

The research and testing reported here meets the following PIER Goals:

- *Providing greater choices for California customers:* By confirming the availability to California customers of a packaged CHP system based on mature power generation technology (spark-ignited, internal combustion engine) capable of operation with exhaust emissions meeting ARB 2007 guidelines, where no such systems have yet to be shown to meet these guidelines.
- *Improving the environment, public health, and safety:* By demonstrating that an internal combustion engine-powered CHP gen set can meet emissions limits imposed on the cleanest power plants operating in California.
- *Improving energy cost/value:* By showing that a high fuel utilization, packaged CHP system based on mature internal combustion engine technology can meet the ARB 2007 emissions guidelines.

## 2.0 Installation and Test Plan

### 2.1. Background

The goal of the testing reported here is to verify that the ENI-85 packaged CHP system, based on a natural gas-fired ICE, manufactured by I Power of Anderson, Indiana, is capable of operating within the emission limits specified by the ARB 2007 distributed generation (DG) emissions guidelines<sup>3</sup>.

The test plan for evaluating the emissions and CHP performance of the ENI-85 packaged CHP generator set was prepared consistent with the Association of State Energy Research and Technology Transfer Institution's (ASERTTI) field test protocols<sup>4</sup> and ARB 2007 emissions measurement protocols.

#### 2.1.1. Test Objective

The specific objective of the work described below is to characterize the operation of the ENI-85 packaged CHP system over 200-300 hours of testing. The overall characteristics of interest for the packaged CHP are:

- The ability to meet the ARB 2007 DG emissions guidelines with advanced engine controls and 3-way exhaust catalyst.
- Quantify the electrical capacity/yield, thermal capacity/yield, and overall fuel use efficiency constrained by meeting the ARB 2007 DG emissions guidelines.
- As operating benefits are likely to exceed operating costs only when the thermal output of the ENI-85 is used to reduce heating fuel purchases, the ability of the unit to follow thermal loads was also qualitatively assessed.

#### 2.1.2. Rationale

No ICE-based CHP system has been pre-certified as meeting the ARB 2007 DG emissions guidelines as of August 2007. The specific emissions limits for pre-certification are listed in Table 2-1. The laboratory testing undertaken by this project was to show that such emissions performance can be achieved by an ICE-powered CHP package.

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<sup>3</sup> Final Regulatory Order Amendments to the Distributed Generation Certification Regulation, California Environmental Protection Agency, Air Resources Board, Stationary Source Division, Project Assessment Branch. August 2007. <http://www.arb.ca.gov/regact/dg06/dg06.htm>.

<sup>4</sup> Distributed Generation and Combined Heat and Power Field Testing Protocol. ASERTTI. October 27, 2004. [http://www.dgdata.org/pdfs/field\\_protocol.pdf](http://www.dgdata.org/pdfs/field_protocol.pdf).

**Table 2-1. ARB 2007 Fossil Fuel Emissions Standard**

<b>Pollutant</b>	<b>Emission Standard (lb/MWh)</b>
NO <sub>x</sub>	0.07
CO	0.10
VOC	0.02

Source: EPRI

The ARB pre-certification guidelines allow units that produce CHP to include both electrical and thermal output when reporting the emission performance. The credit is at the rate of one megawatt hour (MWh) for each 3.4 million British thermal units (Btu) of heat recovered. This is essentially crediting thermal output the same as electrical output. To take the credit, the following must apply:

- The CHP units must be sold with combined-heat-and-power technology integrated into a standardized package.
- The CHP units must achieve a minimum energy efficiency of 60% (useful energy out/fuel in at 100% load) in the conversion of the energy in the fossil fuel to electricity and process heat.

The testing reported here was conducted at the EAC of Southern California Gas Company located in Pico Rivera, California. The EAC installed and operated the system, installed all test instrumentation, collected and analyzed all data, and issued a test data report. Data was collected in support of evaluating electrical performance, electrical efficiency, heat recovery performance and exhaust emissions. The data was collected using procedures consistent with field test protocols published by ASERTTI and emissions measurement protocols consistent with ARB standards.

## **2.2. System Description**

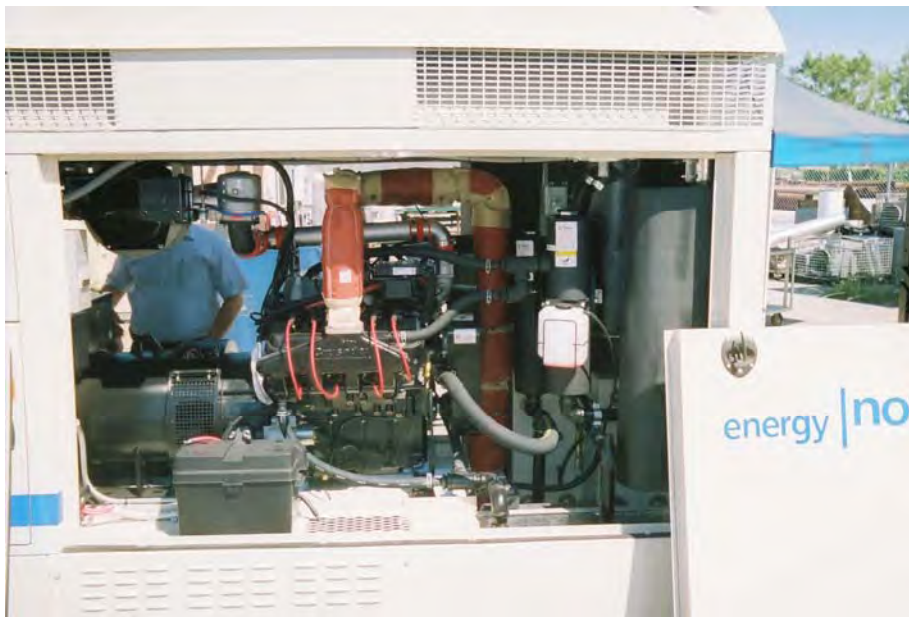
The ENI-85 package, shown in Figure 2-1 at the EAC, is a natural gas-fueled, engine driven generator centered on a GM 8.1 liter industrial engine and state of the art combustion controls. The engine tested is coupled to a synchronous generator, which provides a maximum 85 kilowatts (kW) electrical power at 480 volts alternating current (VAC), 3-phase. The thermal output of the engine coolant water and heat recovered from the engine exhaust is transferred to a secondary loop to serve local thermal loads as shown in Figure 2-2. Table 2-2 summarizes the physical and electrical specifications for the Base Emissions ENI-85 packaged CHP unit, which is I Power's standard commercial product.

The unit tested here was provided with ultra-low emissions features including a higher reduction 3-way catalyst and modified engine control software. The emissions projected by I Power for the ultra-low emissions configuration are listed in Table 2-3.



**Figure 2-1. ENI-85 CHP Package**

Photo Credit: EPRI



**Figure 2-2. ENI-85 Engine, Generator and Heat Recovery Equipment**

Photo Credit: EPRI

**Table 2-2. ENI-85 Base Emissions Specifications<sup>5</sup>**

**ENI 85** Outdoor & Modified For Indoor  
Stoichiometric Continuous Duty Synchronous Generator



**Production Specifications**

Model Number: ENI-0085A-RNSOS

Net Electrical Output	kW	85
Net Electrical Efficiency	%	31
Pkg Efficiency w/ Thermal Heat recovery	%	87.5
Heat Rate (Rated, LHV)	Btu/kWh (kJ/kWh)	10,860 (11,458)
Engine/Generator Type		Continuous Duty Synchronous
Shaft BHP @ ISO	hp (kW)	122 (91)
Operating Speed	rpm	1800
Output Voltage	Vac	277/480 3 Phase
Emissions NOx	g/bhp-hr	0.15
CO	g/bhp-hr	0.60
NMHC	g/bhp-hr	0.15
Sound Level	dB(A)	68 @ 7 meters (std)
Sound Level w/low sound option	dB(A)	60 @ 7 meters
Operating Capability	Blackstart capable in either isolated or grid parallel	
Power Quality THD		Meets IEEE 519
Load Unbalance	%	10% (max)
Overload	%	10% overload allowed 30x/yr w/ 30 min (max) ea
Voltage Regulation Adjust	%	+/-0.5
DC Current Injection	%	<0.5
Fuel Supply Types		Natural Gas
Fuel(LHV)	MMBtu/hr (GJ/hr)	0.944 (0.996)
	cu ft/hr (cu m/hr)	1,014 (28.7)
Supply Pressure	psig (bar)	0.25 - .95 (0.017 - 0.066)
Fuel Standard (LHV)	Btu/cu ft (kJ/cu m)	910 (33,906)
Enclosure Length	in (mm)	120 (3,048)
Width	in (mm)	48 (1,220)
Height	in (mm)	89 (2,248) (Outdoor)
Height	in (mm)	68 (1,727) (Indoor)
		Completely weatherproof (outdoor)
		All units fully lockable
Heat Recovery (CHP)		
Jacket Water Flow	gpm (L/m)	65 (246)
Jacket Water Temp. (out)	deg F (deg C)	183 (84)
Jacket Water Temp. (in)	deg F (deg C)	170 (77)
Heat Gain From Water Jacket	MMBtu/hr (kW)	0.282 (83)
Heat Gained From Exhaust Gas	MMBtu/hr (kW)	0.236 (69)
Total Heat Recovery	MMBtu/hr (kW)	0.518 (152)
Warranty	18 months from delivery or 1 year from initial start up whichever comes first. Extended warranty option available.	
Standards	UL 2200, CSA C22.2	

Notes: These specifications represent the design data as of the publication date listed in the lower right hand corner and may be changed without notice. Please contact I Power Energy Systems LLC for the most current specifications

1. All data based on ISO standard conditions of 29.54 in Hg barometric pressure, 77 deg F ambient and induction air temperatures, 30% rel. humidity
2. Dimensions and weights do not include optional equipment.
3. The values in this specification subject to a tolerance of +/- 5%
4. Efficiency and performance values represent the base unit operating at 100% heat and electrical power. Data is taken at the connection points of the unit.

Issue Date: 5-16-2007

5 ENI 85 Outdoor and Modified for Indoor Stoichiometric Continuous Duty Synchronous Generator Product Specification, I Power Energy Systems, LLC,  
<http://www.ipoweres.com/files/ENI%2085%20Synchronous%20Outdoor%20Specification%205-16-07.pdf>. Note that the emissions performance indicated here is for I Power's standard commercial model. See Table 2-3 for I Power's reported emissions performance of the ultra-low emissions configuration.

**Table 2-3. I Power Reported Ultra-Low Emissions Configuration Performance**

Pollutant	ARB 2007 Limit (lb/MWh)	Exhaust Concentration (@ 0.2% O <sub>2</sub> ) to meet ARB 2007	Measured Exhaust Concentrations (@ 0.2% O <sub>2</sub> )	Calculated Specific Emissions (lb/MWh)
NO <sub>x</sub>	0.07	15 ppm	< 1 ppm	< 0.005
CO	0.10	35 ppm	< 14 ppm	< 0.040
VOC	0.02	4 ppm	< 3 ppm	< 0.015

Source: EPRI

The secondary loop heat transfer fluid (water for these tests) is circulated through the engine heat recovery equipment and the thermal load equipment by a circulation pump external to the engine package. For the purposes of the testing reported here, the thermal load was a dump radiator, shown in Figure 2-3. The thermal load could be varied within limits by adjusting the radiator fan speed with a variable frequency drive.



**Figure 2-3. Dump Radiator**

Photo Credit: EPRI

### **2.2.1. Electrical Output and Grid Connection**

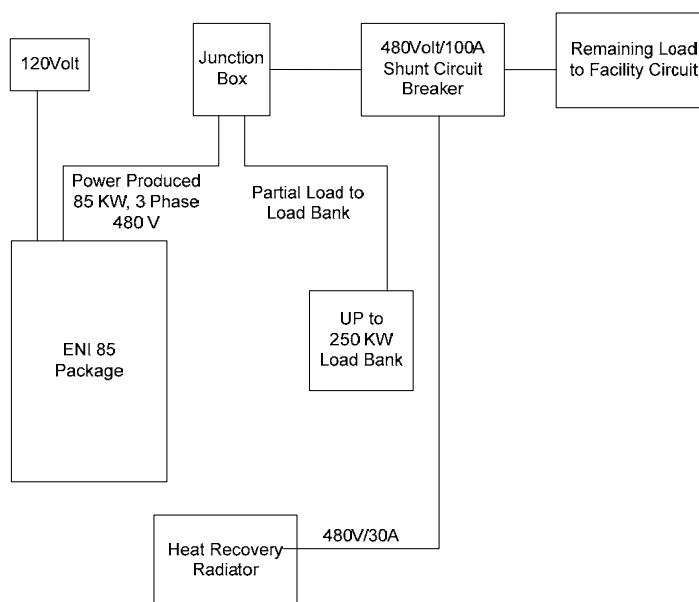
The ENI-85 engine operates at a constant 1,800 revolutions per minute (rpm) and spins a three-phase synchronous generator. The unit was connected to a utility-feed, 480 VAC, 3-phase, 100

Amp circuit to which was also connected, in parallel, a 0-250 kW load bank to absorb some of the generated power. The power connection one-line diagram is shown in Figure 2-4. The natural gas fuel was supplied from within the Southern California Gas Company EAC operating base. Thermal output was absorbed by a dump radiator.

### 2.2.2. System Operating Modes

The ENI-85 can be operated in either Grid Parallel or Grid Isolated Mode.

- *Grid Parallel mode of operation* - The ENI-85 unit acts as a regulated current source and supplies power to the site grid (including the local load bank) while connected to the facility circuit.
- *Grid Isolated mode of operation* - The ENI-85 unit can also be configured and operated as a stand alone generator acting as a regulated voltage source.

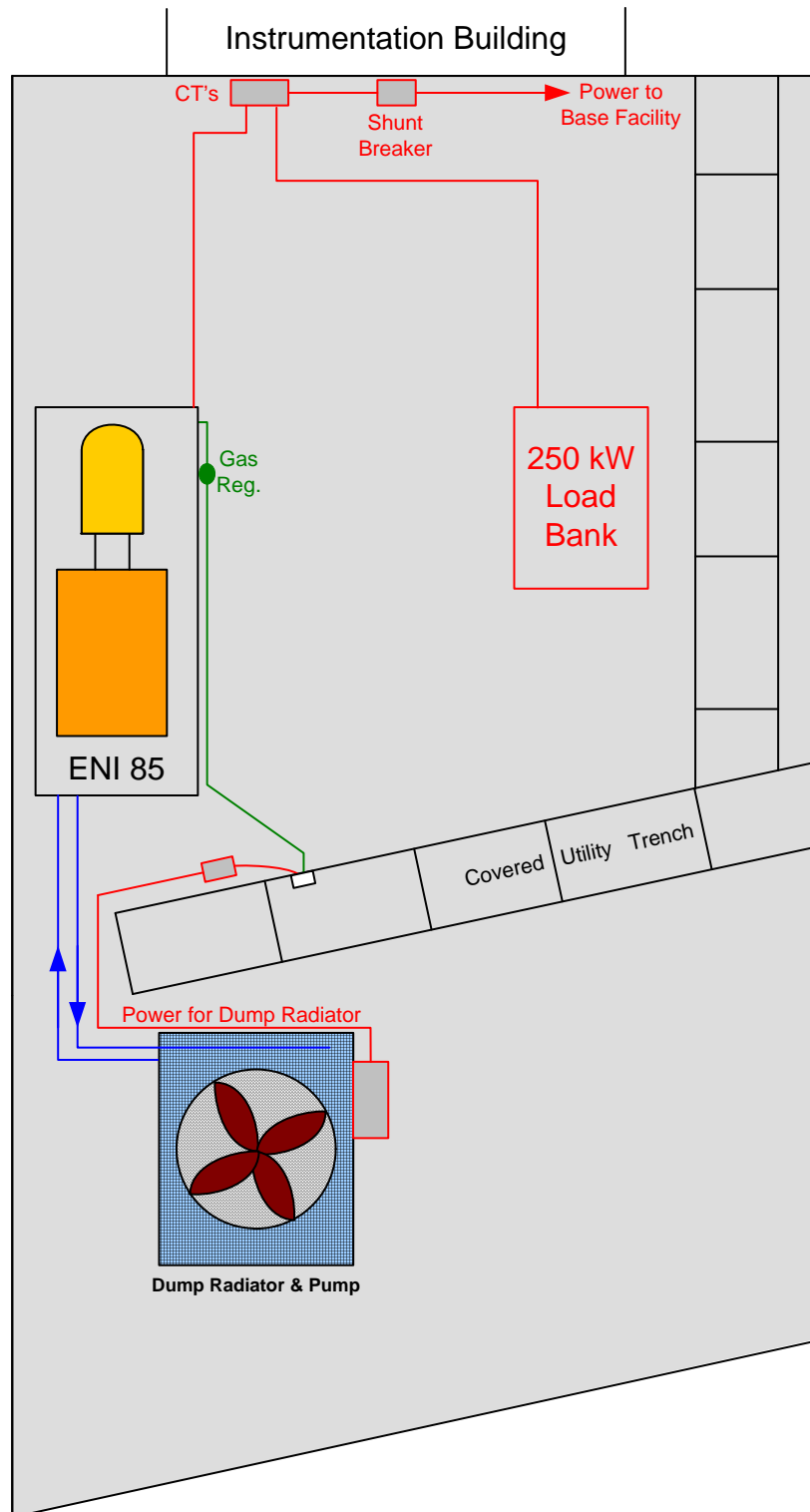


**Figure 2-4. Simplified Site Electrical Diagram**

Source: EPRI/ SoCal Gas

### 2.2.3. Laboratory Facility Description

The laboratory facility used for this test is an outdoor site located within a large operating base. The base has a minimum electric load of more than 100 kW on a 4160 VAC, 3-phase electric utility service. The test facility has multiple electrical circuits available, including the 480 VAC, 3-phase, 100 Amp circuit intended for this test. A natural gas service is available with up to 35 pounds per square inch gauge (psig) delivery pressure and gas quality is continuously monitored with a permanently installed gas chromatograph. Exhaust emission monitoring is available with a mobile emission monitoring van. A plan view for the test site is shown in Figure 2-5.



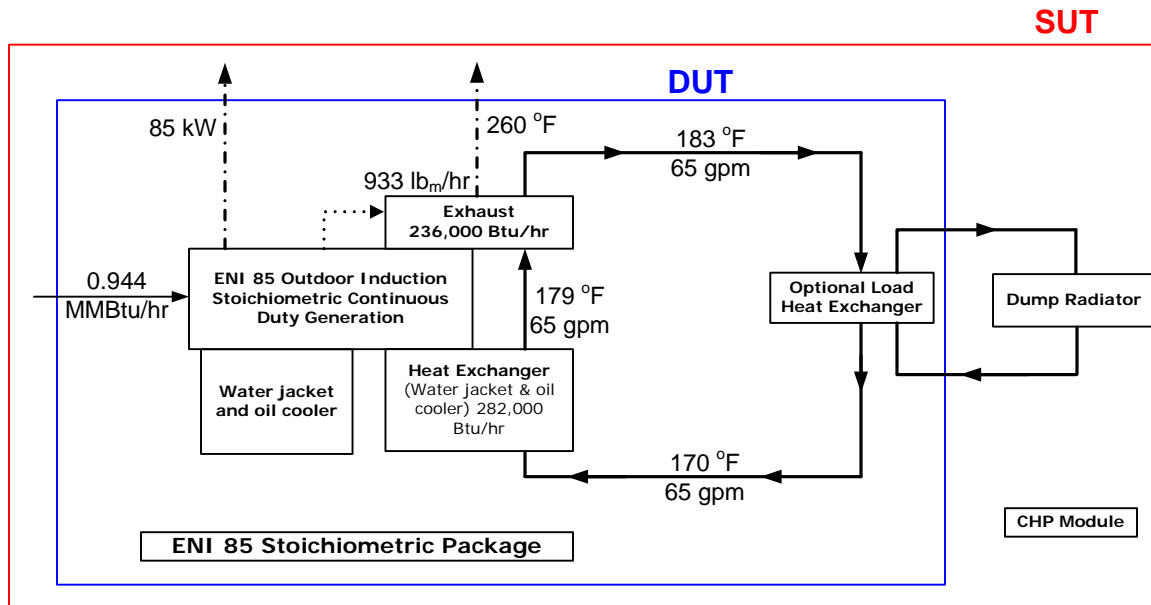
**Figure 2-5. Test Site Layout**

Source: EPRI/ SoCal Gas

## 2.3. Test Conduct

### 2.3.1. System Boundary

The ENI-85 unit test was limited to the performance of the system under test (SUT). Figure 2-6 illustrates the SUT boundary for this test. Within the SUT boundary is the device under test (DUT) or product boundary, which includes the CHP unit and all of the internal components. In addition to the DUT, the SUT includes the CHP water circulating pump, the only significant external electric parasitic load on the system. Also within the SUT is the dump radiator used to discharge the waste heat.



**Figure 2-6. ENI-85 kW CHP Boundary Diagram**

Source: EPRI/ SoCal Gas

### 2.3.2. Operating Modes

In general, the unit was operated in either a dispatched electrical output mode or a thermal load following mode. In the thermal load following mode, the generator produces electrical power consistent with the demand for the waste engine heat. When the thermal load changes, the unit automatically adjusts the power output by changing fuel flow.

### 2.3.3. Test Measurements

The following parameters were monitored during the tests:

- Electrical Output and efficiency
- CHP Thermal Output and efficiency
- Exhaust Emissions

### ***Electrical Performance Data Set***

The following parameters were measured to determine the electrical performance:

- Real Power, Kilowatts (kW)
- Apparent power, Kilo-Volt-Amperes (kVA) Apparent
- Reactive power, Kilo-Volt-Amperes Reactive (kVAR)
- Power factor, Cosine of Phi (CoSPhi)
- Phi, Angle between Real Power and Apparent Power Vectors
- Voltage total harmonic distortion (snapshot), Percent (%)
- Current total harmonic distortion (snapshot), Percent (%)
- Frequency, Hertz (Hz)
- Voltage, Volts (V)
- Current, Amperes (A)

These parameters were measured with a digital power logger. The logger scans all power parameters once every three seconds and computes and records one minute averages. The unit operated continuously during the test period. The stated logger accuracy is better than 1%. (Note: Measurement of the harmonic distortion with this unit is not continuous.)

### ***Electrical Efficiency Data Set***

The following parameters were measured to determine the electrical efficiency:

- Real power production, kW
- External parasitic load power consumption, kW
- Ambient temperature, °F
- Ambient barometric pressure, pounds-force per square inch absolute (psia)
- Fuel Lower Heating Value (LHV), Btu per standard cubic foot (scf)
- Fuel consumption, standard cubic feet per hour (scfh)

Real power production was measured by the digital power monitor. Ambient temperature was measured by a 4-wire platinum resistance temperature detector (RTD). The specified accuracy of the RTD is  $\pm 0.4^{\circ}$  F. The ambient barometric pressure was measured by a Druck pressure transducer with a specified accuracy of  $\pm 1\%$  of full scale.

Gas flow was measured by a Roots Model 15C175 Meter with a specified accuracy of  $\pm 1\%$ . Gas temperature was measured by a 4-wire RTD as described above. Gas pressure was measured by a Druck pressure transducer with a specified accuracy of  $\pm 1\%$  of full scale. Gas composition was measured with a Daniels Model 500 Series gas chromatograph with a 2350A controller. The specified accuracy is  $\pm 0.5$  Btu per 1000.

The external parasitic load introduced by the heat transfer fluid circulation pump was monitored using a portable power data logger.

### ***CHP Performance Data Set***

The following parameters were measured to determine the CHP performance:

- Secondary heat transfer loop water flow, gallons per minute (gpm)
- Dump radiator inlet temperature, °F
- Dump radiator outlet temperature, °F

The heat recovery rate was calculated throughout the test period. A hot water flow meter with a verified accuracy of  $\pm 1\%$  and 1 pulse per 10 gallons was used to measure the fluid flow rate. 4-wire RTD's were used to measure the fluid temperatures at the DUT inlet and outlet connections.

### ***Emissions Performance Data Set***

Gaseous emissions and pollutants were measured three times at or near 50%, 75%, and 100% rated power output. The test operations were conducted for a minimum of one-half hour during steady-state operation of the CHP unit. The measurements were made concurrent with the electrical and CHP performance tests. Emissions of interest are:

- Nitrogen oxides (NO<sub>x</sub>)
- Carbon monoxide (CO)
- Carbon dioxide (CO<sub>2</sub>)
- Oxygen (O<sub>2</sub>)
- Total hydrocarbons (THC)
- Volatile Organic Compounds (VOC)

Emissions testing for the first five components listed were performed by EAC personnel using ARB Test Methods. The VOC emissions were collected in sample bags and then analyzed by an outside laboratory using EPA Method 18. Results for each pollutant are reported in units of parts per million (ppm) corrected to 15% O<sub>2</sub>, lb/hr, and lb/MWh.

#### ***2.3.4. Laboratory Test Procedures and Site-Specific Instrumentation***

Site specific measurement instrumentation is listed in Appendix A. The DUT was operated at full load for 190 hours prior to commencement of the specific test procedures.

Three separate test scenarios were used. First, after the initial 190-hour break-in period, emission tests were conducted to collect detailed data under controlled, steady-state conditions. Then, continuous operation under thermal load-following conditions for approximately one week was undertaken. Data were also collected to characterize sequences of operation during two start-up sequences to determine changes in electrical output, fuel consumption and the flows and temperatures of the heat recovery fluid. The operational tests are listed in Table 2-4 and are described further below.

### **Steady State Controlled-Load Test Procedures**

The electrical output was adjusted at the package controller during three controlled-load tests. At each load level, data was collected over three (3) periods of one-half hour each. All electrical performance, electrical efficiency, CHP performance, and emissions performance tests were conducted simultaneously. Emission data for each test run included pre- and post-test calibration, drift, linearity and other quality assurance/quality control (QA/QC) checks.

**Table 2-4. Test Matrix**

<b>Test</b>	<b>Duration</b>	<b>Fuel Data Set</b>	<b>Electrical Data Set</b>	<b>Thermal Data Set</b>	<b>Continuous Emissions</b>	<b>VOC Emissions</b>
Run-in	190 hrs	X	X	X	Spot checks	
<b>Steady State Tests</b>						
100%	3 x ½ hour	X	X	X	X	X
75%	3 x ½ hour	X	X	X	X	X
50%	3 x ½ hour	X	X	X	X	X
Long Term Thermal Load Following	170 hours	X	X	X	Spot checks	
<b>Sequence of Operations</b>						
Cold Start	Twice	X	X	X	X	

Source: EPRI/ SoCal Gas

The step-by-step procedure is as follows:

1. Ensure all instruments are properly installed and calibrated in accordance with the manufacturer's specifications.
2. Start all emission analyzers and let them warm up for at least one hour.
3. Synchronize all clocks and data logging timers.
4. Initialize the data logger(s) and begin recording average data.
5. Calibrate and perform linearity checks as required for the emission instruments.
6. Start the unit and operate at 100%, 75% and 50% load and monitor both power and thermal output.
7. At the end of each half hour test, verify the completeness and reasonableness of all data. Perform calibration and linearity checks on emission instruments as required.

8. At the end of each day of testing, digitally scan all log and other paper forms and save them with all digital data files. All data will be saved on hard disk and on removable discs each day.

### ***Long-Term Thermal Load-Following Test Procedures***

During the thermal load-following tests, the thermal load changed due to normal ambient temperature variations. This enabled analysis of the unit performance. All unit performance parameters were measured during the test period (except start-up and shut-down specific events).

### ***Sequence of Operations Test Procedures***

During the normal Start-up test, data collection intervals were reduced to one second for the SUT. Data collection started prior to the Start command and continued until power production, fuel consumption and waste heat recovery reached steady-state conditions.

### ***2.3.5. Data Acquisition and Reporting***

#### ***Electronic Data***

Electronic data were monitored for the following measurements:

- Power output and power quality parameters
- Parasitic load of the circulation pump
- Fuel flow, LHV, pressure, and temperature
- Transfer fluid flow, supply temperature, and return temperature
- Ambient temperature and barometric pressure

A Delphin Technology data logger recorded all of the temperature, pressure, and flow meter data once every second and calculated and recorded one-minute averages throughout all tests.

The fuel LHV was calculated and recorded every hour by the Daniel gas chromatograph.

The electronically recorded one-minute averages were the source data for all calculated results.

#### ***Documentation***

All events not specifically included in the digital data files relative to the tests were recorded on the log forms and will include:

- Starting and ending times for tests
- Runs, notes, and so forth.
- Copies of calibrations and manufacturers' certificates

The EAC archived all electronic data, paper files, analyses, and reports at their Pico Rivera, California office in accordance with their internal procedures.

### ***Test Data Report***

At the conclusion of testing, a test data report was issued by the EAC to the project principals<sup>6</sup>. The report summarized each test parameter's results and contained sufficient raw data to support findings and allow others to assess data trends, completeness, and quality. The data reported here was taken from this test data report.

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<sup>6</sup> Firas Hamze, R. Schwedler, *Distributed Generation Test Report I-Power ENI-85 kW at Southern California Gas Company*, Southern California Gas Company, July 2007.



## 3.0 Test Results

The ENI-85 unit was commissioned on May 15, 2007, and operated under varying conditions for more than 650 hours. Several issues were encountered and resolved during the first few weeks of operation. The steady state tests were conducted between June 18 and June 20, 2007, after the unit had operated more than 190 hours. The startup tests were conducted during the same period. The Continuous Test data were then collected while the unit operated on a preset thermal load profile.

Overall, the I Power ENI-85 unit full load fuel use was about 5% greater than the manufacturer's specification and the measured fuel utilization efficiency (electrical + thermal) was 78.9% compared to a claimed 85%. Power delivered by the ENI-85 was as advertised, approximately 85.5 kW, net.

In general, the ENI-85 unit is a well built and reliable unit. It operated smoothly once all the set-points and initial configuration settings were programmed. The most significant issues were stabilizing the unit emissions at various power output loads and setting the thermal load following process proportional–integral–derivative (PID) controller.

### 3.1. Steady-State Controlled Load Test Results

#### 3.1.1. Steady-State CHP Performance

Table 3-1 summarizes the power output, heat production, and efficiency performance of the ENI-85 unit for the three different electric test load sets. Each test load set consisted of three half-hour runs. The fuel input and the power performance at the test load were consistent for all three half-hour test runs. The fuel input rate for the three half-hour 100% load tests was 5.5% higher than specified which resulted in a gross generating efficiency of 29.3% LHV. As for the 75% and 50% load test, both electrical and gas input performance were consistent among each of the half-hour runs. Electrical efficiency dropped to 27.5% during the 75% load test and 23.5% during the 50% load test. The thermal performance during the 100% load half-hour tests was 4% lower than specified, averaging 49.6%. The 100% load thermal efficiency and the generating efficiency resulted in a Total System Efficiency of 78.9% versus 85.5% in the specifications. Thermal load efficiency increased when the electric load dropped; averaging 54.4% thermal efficiency during the 50% load test runs.

#### 3.1.2. Steady-State Electrical Performance

The electrical performance results are summarized in Table 3-2. The power generated from the ENI-85 unit was fed into the facility circuit and a load bank. Site electrical conditions restricted the amount of power that could be exported to the facility circuit; therefore, over 90% of the power produced was dumped into an electrical load bank.

**Table 3-1. ENI-85 CHP Electrical and Thermal Performance (Controlled Half-Hour Tests)**

Test Load	Test Run	Gas Input (1,000 Btu/hr)	Electrical Power Generation Performance				Heat Recovery Performance		Fuel Utilization Efficiency (% fuel input)	Ambient (°F)
			Electric Output (kW)*	Power to Local Grid (kW)	Power to Load Bank (kW)	Electrical Efficiency (%)	Heat Recovery (1,000 Btu/hr)	Thermal Recovery (% fuel input)		
<b>100%</b>	<b>1</b>	<b>989.5</b>	<b>85.4</b>	<b>4.0</b>	<b>81.4</b>	<b>29.5</b>	<b>492.0</b>	<b>49.7</b>	<b>79.2</b>	<b>74.7</b>
	<b>2</b>	<b>996.8</b>	<b>85.5</b>	<b>4.6</b>	<b>80.9</b>	<b>29.3</b>	<b>494.7</b>	<b>49.6</b>	<b>78.9</b>	<b>76.4</b>
	<b>3</b>	<b>1000.7</b>	<b>86.0</b>	<b>4.0</b>	<b>82.1</b>	<b>29.1</b>	<b>498.8</b>	<b>49.5</b>	<b>78.6</b>	<b>82.6</b>
	Avg	995.7	85.6	4.2	81.5	29.3	495.2	49.6	78.9	77.9
<b>75%</b>	<b>1</b>	<b>796.4</b>	<b>64.0</b>	<b>3.9</b>	<b>60.1</b>	<b>27.4</b>	<b>411.1</b>	<b>51.6</b>	<b>79.0</b>	<b>81.4</b>
	<b>2</b>	<b>801.1</b>	<b>64.2</b>	<b>4.1</b>	<b>60.1</b>	<b>27.3</b>	<b>418.5</b>	<b>52.2</b>	<b>79.6</b>	<b>85.5</b>
	<b>3</b>	<b>787.4</b>	<b>64.1</b>	<b>4.6</b>	<b>59.4</b>	<b>27.7</b>	<b>413.6</b>	<b>52.5</b>	<b>80.3</b>	<b>87.5</b>
	Avg	795.0	64.1	4.2	59.9	27.5	414.4	52.1	79.6	84.8
<b>50%</b>	<b>1</b>	<b>617.2</b>	<b>42.0</b>	<b>5.1</b>	<b>36.9</b>	<b>23.2</b>	<b>332.3</b>	<b>53.8</b>	<b>77.0</b>	<b>83.6</b>
	<b>2</b>	<b>607.1</b>	<b>42.1</b>	<b>5.3</b>	<b>36.8</b>	<b>23.7</b>	<b>336.4</b>	<b>55.4</b>	<b>79.1</b>	<b>86.9</b>
	<b>3</b>	<b>610.5</b>	<b>42.5</b>	<b>5.1</b>	<b>37.3</b>	<b>23.7</b>	<b>330.2</b>	<b>54.0</b>	<b>77.8</b>	<b>87.0</b>
	Avg	611.6	42.2	5.2	37.0	23.5	333.0	54.4	78.0	85.8

\*Sum of actual power delivered to the facility grid and power dissipated in the load bank.

Source: EPRI/ SoCal Gas

**Table 3-2. ENI-85 Electrical performance (Controlled Half-Hour Tests)**

Electrical Performance		100 % Load	75% Load	50% Load
Real Power, kW	<b>Load Bank</b>	<b>81.4</b>	<b>59.9</b>	<b>37.0</b>
	<b>Facility Circuit</b>	<b>4.2</b>	<b>4.2</b>	<b>5.2</b>
	<b>Total kW</b>	<b>85.6</b>	<b>64.1</b>	<b>42.2</b>
Apparent Power, kVA	<b>Load Bank</b>	<b>81.4</b>	<b>59.9</b>	<b>37</b>
	<b>Facility Circuit</b>	<b>10.8</b>	<b>10</b>	<b>11</b>
	<b>Total kVA</b>	<b>92.2</b>	<b>69.9</b>	<b>48</b>
Reactive Power, kVAR	<b>Load Bank</b>	<b>1.0</b>	<b>0.6</b>	<b>0.1</b>
	<b>Facility Circuit</b>	<b>9.9</b>	<b>9.1</b>	<b>9.7</b>
	<b>Total kVAR</b>	<b>10.9</b>	<b>9.7</b>	<b>9.8</b>
Power Factor	<b>Load Bank</b>	<b>0.99</b>	<b>0.99</b>	<b>0.99</b>
	<b>Facility Circuit</b>	<b>0.39</b>	<b>0.42</b>	<b>0.47</b>
Voltage, V	<b>Load Bank</b>	<b>475.4</b>	<b>474.7</b>	<b>474.6</b>
	<b>Facility Circuit</b>	<b>475.6</b>	<b>474.8</b>	<b>475.0</b>
Current, A	<b>Load Bank</b>	<b>96.6</b>	<b>71.5</b>	<b>43.3</b>
	<b>Facility Circuit</b>	<b>12.8</b>	<b>11.9</b>	<b>13.1</b>

Source: EPRI/ SoCal Gas

**3.1.3. Steady-State Thermal Performance**

The heat recovery results are summarized in Table 3-3. The secondary heat transfer loop fluid flow rate averaged 61.7 gpm during the load tests. The return water temperature to the engine rose when the electrical output of the generator dropped. The rise in water temperature is caused by the radiator control system trying to adjust the fan speed according to the supply water temperature. The supply water temperature remained consistent throughout the different test loads, averaging 183.3° F. The heat recovery rate averaged 495,200 Btu/hr at full electrical load, which is about 4% lower than specified. The heat recovery rate for the 75% and 50% load averaged 414,000 and 333,000 Btu/hr, respectively.

**Table 3-3. ENI-85 Heat Recovery Conditions (Controlled Half-Hour Tests)**

Test Load	Test Run	Thermal Heat Recovery Loop Performance			
		Water Flow Rate (GPM)	Supply Water Temperature(°F)	Return Water Temperature(°F)	Heat Recovery Rate (thousand Btu/hr)
<b>100%</b>	<b>1</b>	<b>62.2</b>	<b>183.5</b>	<b>167.6</b>	<b>492.0</b>
	<b>2</b>	<b>62.7</b>	<b>183.4</b>	<b>167.5</b>	<b>494.7</b>
	<b>3</b>	<b>59.5</b>	<b>183.1</b>	<b>166.3</b>	<b>498.8</b>
	Avg.	61.5	183.3	167.1	495.2
<b>75%</b>	<b>1</b>	<b>63.0</b>	<b>183.4</b>	<b>170.3</b>	<b>411.1</b>
	<b>2</b>	<b>63.8</b>	<b>183.4</b>	<b>170.3</b>	<b>418.5</b>
	<b>3</b>	<b>58.3</b>	<b>183.0</b>	<b>168.8</b>	<b>413.6</b>
	Avg.	61.7	183.3	169.8	414.4
<b>50%</b>	<b>1</b>	<b>63.3</b>	<b>183.4</b>	<b>172.9</b>	<b>332.3</b>
	<b>2</b>	<b>64.0</b>	<b>183.2</b>	<b>172.7</b>	<b>336.4</b>
	<b>3</b>	<b>58.0</b>	<b>183.2</b>	<b>171.8</b>	<b>330.2</b>
	Avg.	61.8	183.3	172.5	333.0

Source: EPRI/ SoCal Gas

**3.1.4. Steady-State Exhaust Emissions**

Detailed emissions steady state emissions test data is contained in Appendix B with the emissions equipment calibration data in Appendix C. VOC sampling was conducting by slowly filling two Tedlar bags during each 30 minute test run. The detailed VOC lab analysis reports are contained in Appendix D.

**Table 3-4. ENI-85 CHP Emissions**

Test Load	Test Run	O <sub>2</sub> (%)	CO <sub>2</sub> (%)	NO <sub>x</sub> Emissions		CO Emissions		VOC Emissions	
				ppmv at 15 % O <sub>2</sub>	Pounds per MWhr	ppmv at 15 % O <sub>2</sub>	Pounds per MWhr	ppmv at 15 % O <sub>2</sub>	Pounds per MWhr
100%	Run1	0.00	12.17	2.66	0.0459	8.68	0.091	<0.5	0.0008
	Run2	0.00	12.16	1.70	0.0294	7.63	0.080	<0.5	0.0009
	Run3	0.00	12.13	2.14	0.0372	6.37	0.067	<0.5	0.0009
	Avg.	0.00	12.15	2.17	0.0375	7.56	0.079	<0.5	0.0009
75%	Run1	0.00	12.17	2.49	0.043	11.99	0.126	<0.5	0.0008
	Run2	0.00	12.17	2.84	0.0488	7.93	0.083	<0.5	0.0008
	Run3	0.00	12.16	4.04	0.0688	3.44	0.036	<0.5	0.0008
	Avg.	0.00	12.17	3.12	0.0535	7.79	0.081	<0.5	0.0008
50%	Run1	0.00	12.21	1.30	0.023	11.83	0.127	<0.5	0.0009
	Run2	0.00	12.13	0.89	0.015	9.94	0.105	<0.5	0.0008
	Run3	0.00	12.16	2.77	0.049	4.12	0.044	<0.5	0.0009
	Avg.	0.00	12.17	1.65	0.029	8.63	0.092	<0.5	0.0009
Weighted Average <sup>7</sup>					0.044		0.083		0.00085
ARB 2007 Requirement					0.070		0.100		0.02000

Source: EPRI/ SoCal Gas

### 3.1.5. Power Quality

Table 3-5 summarizes the power quality statistics of the system for three different load outputs. Instantaneous readings of the 3<sup>rd</sup>, 5<sup>th</sup> and 7<sup>th</sup> harmonic frequencies were obtained for each of the load tests. Each of the harmonic frequency value is based on two different channels that represent two of the unit circuit phases. Standard deviation (SD) values between the phases are also listed in the table. Voltage Total Harmonic Distortion (THD) and Current THD are shown as a percentage of the fundamental.<sup>8</sup>

<sup>7</sup> 100% load emissions times 0.3 plus 75% load emissions times 0.5 plus 50% load emissions times 0.2

<sup>8</sup> Institute of Electrical and Electronic Engineers. 1989. *IEEE Recommended Practice: Test Procedure for Utility Interconnected Static Converters*, IEEE 1035-1989, Piscataway, NJ; Institute of Electrical and Electronic Engineers

While in Grid Parallel mode of operation, the following was performed via the Woodward EGCP-2 Controller:

- Over/under voltage
- Over/under frequency
- Reverse power
- Over current

**Table 3-5. ENI-85 CHP Harmonics (Controlled Half-Hour Tests)**

Harmonic Frequency	Harmonic/Waveform Values		100% Load		75% Load		50% Load	
			Avg.	SD <sup>1</sup>	Avg.	SD <sup>1</sup>	Avg.	SD <sup>1</sup>
3 <sup>rd</sup>	Frequency		180	-	180	-	180	-
	Volts	Vrms	489.1	0.70	484.45	0.89	486.9	1.05
		THD %F <sup>2</sup>	2.4	0.08	2.6	0.08	2.4	0.06
	Amps	Arms	104.3	3.70	85.7	4.70	57.5	5.25
		THD %F <sup>2</sup>	6.25	0.11	7.2	0.40	11.9	1.40
5 <sup>th</sup>	Frequency		300	-	300	-	300	-
	Volts	Vrms	490.0	2.50	484.4	0.87	487.5	0.85
		THD %F <sup>2</sup>	2.6	0.15	2.4	0.07	2.38	0.02
	Amps	Arms	103.9	3.80	80.2	3.40	54.2	3.84
		THD %F <sup>2</sup>	6.3	0.13	7.6	0.35	12.6	1.25
7 <sup>th</sup>	Frequency		420	-	420	-	420	-
	Volts	Vrms	489.9	2.60	483.6	0.98	488.2	0.55
		THD %F <sup>2</sup>	2.3	0.05	2.5	0.11	2.6	0.06
	Amps	Arms	104.2	3.40	79.9	3.78	54.4	3.50
		THD %F <sup>2</sup>	6.2	0.14	7.7	0.36	12.5	1.20

<sup>1</sup> SD = Standard deviation of two of the phases measured for power monitoring.

<sup>2</sup> %F = Percentage of the fundamental (IEEE Standard 1035-1989)

Source: EPRI/ SoCal Gas

### 3.2. Start-Up Sequence of Operations

Table 3-6 shows the results for the two start-up tests. The two tests were conducted to observe the performance of the ENI-85 during engine start up conditions. The data presented in Table 3-6 include the first 30-minute average data after the engine start up. The unit was warmed up for at least one hour before starting any of the load tests; however the unit took about 30 minutes to stabilize its power output at 85 kW. Moreover, it was noticed that the unit took about 5 minutes longer to start producing power when both the load bank and the ENI-85 unit were started simultaneously. The unit power output fluctuated between 71 and 96 kW in the first 30 minutes of operation. Exhaust emissions were unstable throughout the start up period and remained so for at least one hour after start up. The difference between Test 1 and Test 2 fuel consumption was caused by the unit delayed power production, which also in turn affected the CHP performance.

**Table 3-6. ENI-85 Start-Up Data**

Test Number	Time Start to Power Export	Total Time to Stabilize Power Output	Power Output Variation During Startup		Average Emissions		Thermal Output	Fuel Use
					NO <sub>x</sub>	CO	Heat Recovery	Gas Input
	Minutes	Minutes	Low kW	High kW	pounds per MWh		thousand Btu/hr	
1	9	28	70.9	96.1	0.4478	0.2087	271.9	680.8
2	5	29	71.5	94.9	0.1778	0.1772	397.4	925.9
ARB 2007 Steady State Requirement					0.07	0.10		

Source: EPRI/ SoCal Gas

### 3.3. Long-Term Thermal Load-Following Test Results

At the conclusion of each 30 minute test , the ENI-85 unit was set to operate in the thermal load following mode. I-Power does not commercially offer a thermal load-following control for the ENI-85. A load-following strategy was implemented in the field, for these tests only, in consultation with I-Power personnel.

The thermal load following controller monitored the return water temperature to the CHP unit and compared it to the (constant) temperature control set point. When the water temperature exceeded the control's temperature set point, the temperature controller reduced the generator electrical output set point to adjust for the water temperature change, and vice versa when the return water dropped below the control's temperature set point.

The speed of the fan serving the radiator used to dump the generator thermal load was switched to manual during the thermal load-following mode test and fixed to operate at a constant 18.5 Hz. Thus, the heat load associated with the radiator changed during the day as the ambient temperature changed.

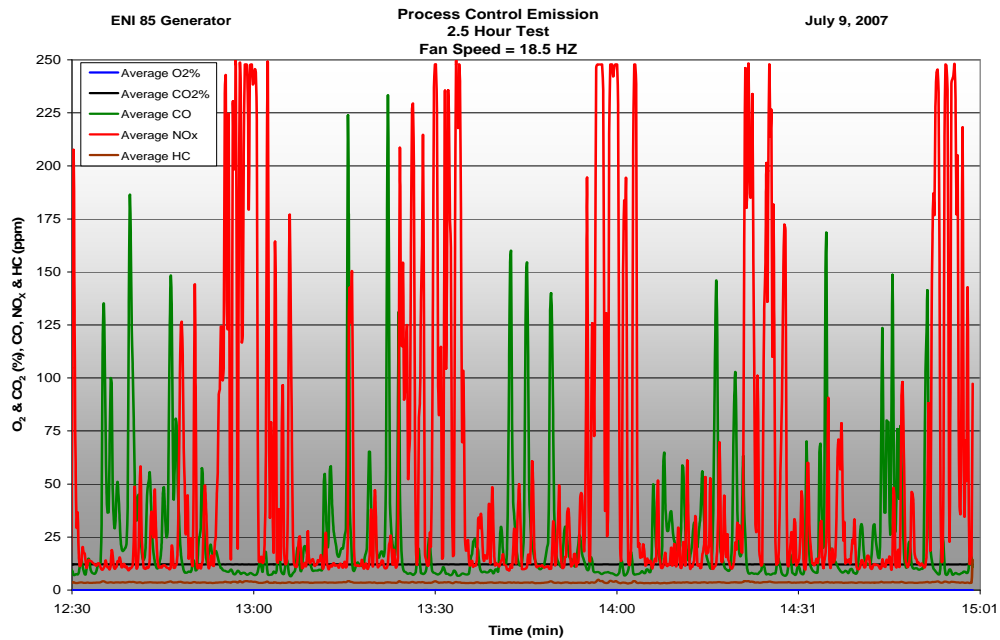
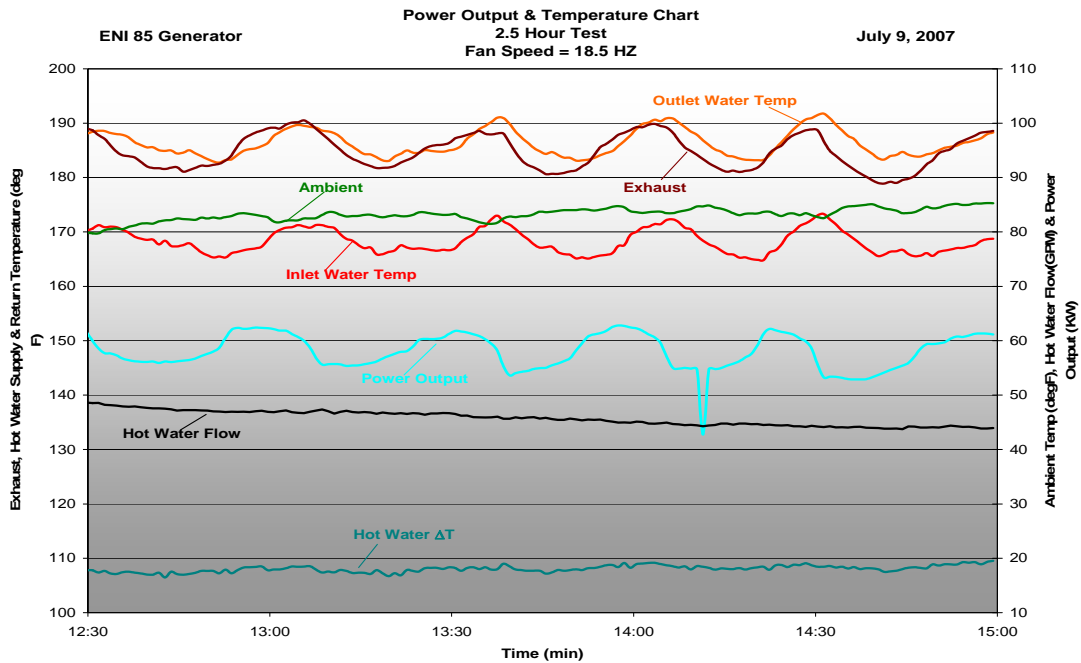
During the week of continuous operation, it was observed that the generator electrical output control was constantly hunting for the control's temperature set point and was unable to stabilize the generator output and the exhaust emissions. Per manufacturer recommendations, a few adjustments were made to the temperature controller to increase the system stability; however, the desired outcome was not achieved. The generator stability slightly improved with the new adjustment; yet, the exhaust emissions continued to be unstable throughout the test.

The data in Figure 3-1 show an example of the generator operation over a 2½-hour period. The ambient temperature increased 6° F during the period displayed. The generator power output was directly proportional to the inlet water temperature and varied from 43 kW to 63 kW. The unit emission constantly fluctuated during the test; the NO<sub>x</sub> emissions ranged from 9 ppm to over 250 ppm, exceeding the emission analyzer limits at times. The CO emissions ranged from 7 ppm to 233 ppm and O<sub>2</sub>, CO<sub>2</sub>, and HC remained constant throughout the test and averaged 0%, 12.1% and 3.6 ppm, respectively.

Using the ambient temperature changes as the thermal load profile, Figure 3-2 shows a 24 hour period (midnight to midnight) of the generator operation and the relationship between the engine's parameters and the ambient temperature. The oscillations in electrical (and thermal) output are typical of "hunting" for a stable operating point; each response of the engine-generator, whether to increase load or decrease load, consistently overshoots the temperature set point.

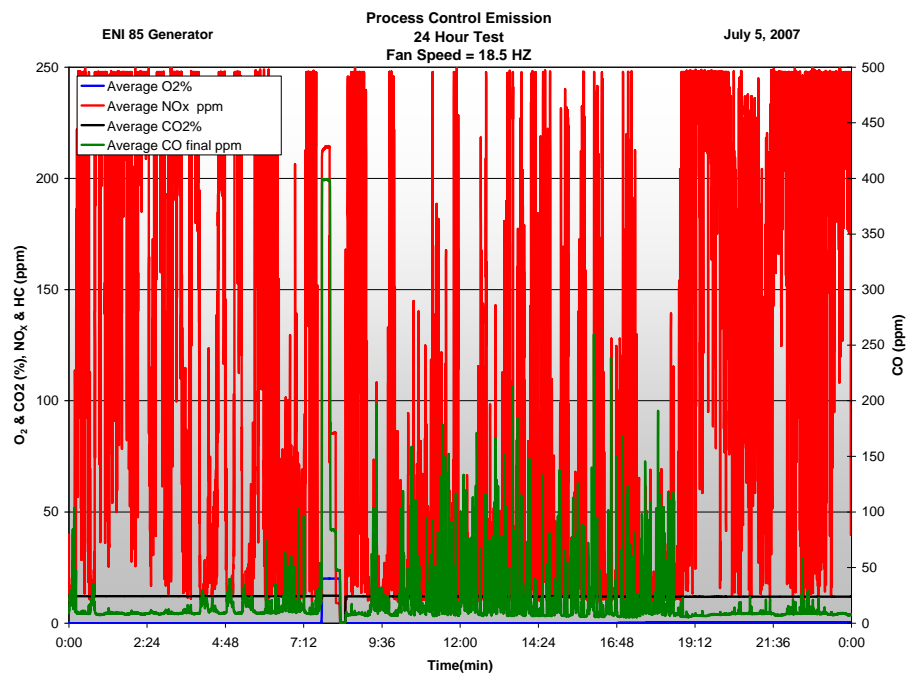
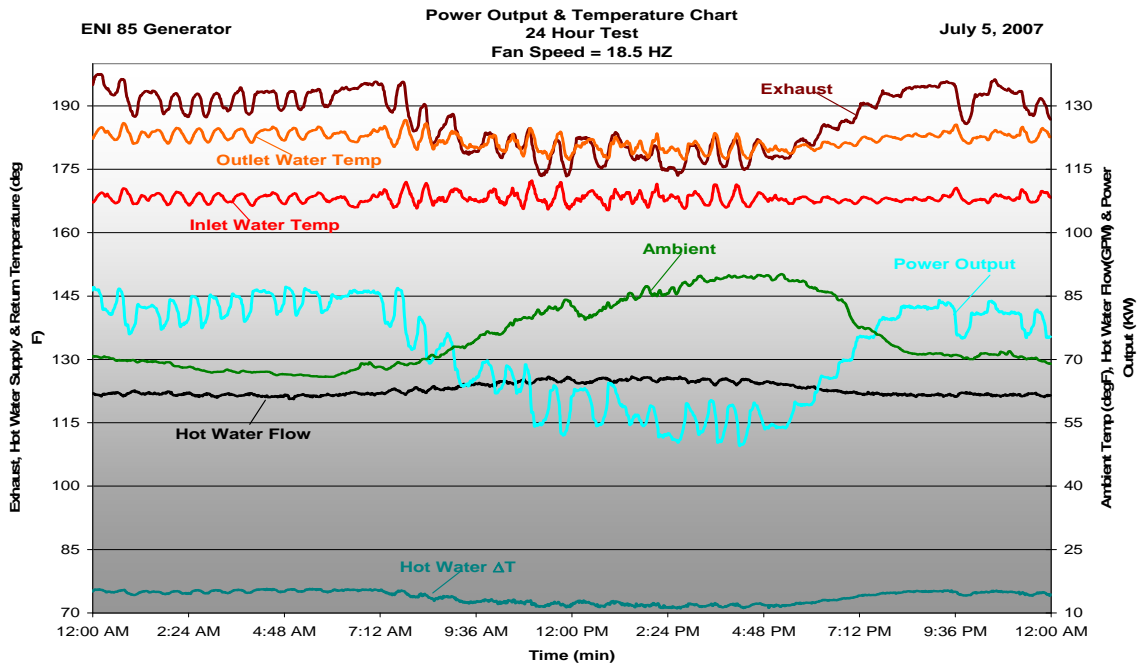
The unit did, generally, follow the thermal load as indicated by the drop in the power output in the middle of the day, due to the reduction in heat load associated with an ambient temperature increase. The longest stable power output period occurred near 6:50 AM and 9:00 PM where the power output remained steady for at least half hour. NO<sub>x</sub> emissions exceeded the emission analyzer range (250 ppm) for most of the test period. CO emissions averaged 19 ppm throughout the test period.

It is clear that additional work in unit controls will be necessary to achieve stable electrical operation and, at the same time, low emissions in thermal load-following mode.



**Figure 3-1. Thermal Load Following Test Results – 2.5 Hour Period**

Source: EPRI/ SoCal Gas



**Figure 3-2. Thermal Load Following Test Results – 24 Hour Period**

Source: EPRI/ SoCal Gas

## 4.0 Conclusions and General Observations and Recommendations

### 4.1. Conclusions

The primary objective of this project was to collect operating and emission data for the ENI-85 system and to report on the operating characteristics. The individual data points were used to evaluate electrical performance, electrical efficiency, heat recovery performance, and exhaust emission levels to simultaneously confirm: (1) the ability of the ENI-85 to meet the ARB 2007 emissions guidelines, and (2) to quantify the overall fuel efficiency of the ENI-85 when operating as a CHP plant.

The actual heat recovery during the half-hour tests ranged from 495,200 Btu per hour at the 100% electrical load to 333,000 Btu per hour at the 50% electrical load or 49.9% and 54.5% of the total heat input, respectively. The generator fuel use efficiency averaged near 78.5% throughout the test at all loads.

The exhaust emission test results showed that the ENI-85 average emission values of three (3) steady state load level runs met the ARB 2007 emissions standard requirements. The ENI-85 calculated emission rates<sup>9</sup> were:

- NO<sub>x</sub>: 0.044 lb/MWh (ARB 2007 Requirement is 0.07 lb/MWh)
- CO: 0.083 lb/MWh (ARB 2007 Requirement is 0.10 lb/MWh)
- VOC: 0.00085 lb/MWh (ARB 2007 Requirement is 0.02 lb/MWh)

It is worth noting that the most recent version of the emission standard, effective in August 2007, does not apply this weighted calculation to engine load factor<sup>10</sup>. Only the emissions results at 100% load are considered. The ENI-85 calculated emission rates according to this requirement were:

- NO<sub>x</sub>: 0.0375 lb/MWh (ARB 2007 Requirement is 0.07 lb/MWh)
- CO: 0.079 lb/MWh (ARB 2007 Requirement is 0.10 lb/MWh)
- VOC: 0.0009 lb/MWh (ARB 2007 Requirement is 0.02 lb/MWh)

Using either method, the ENI-85 met the ARB 2007 emissions pre-certification requirement.

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<sup>9</sup> A weighted calculation applying 30% factor to full load emissions, 50% factor to 75% load emissions, and 20% factor to half load emissions results (on a lb/MWh basis) and was the requirement in place when this test program was initiated. See Section 94207-d(5), Division 3 of Title 17, California Code of Regulations

<sup>10</sup> *Final Regulatory Order Amendments to the Distributed Generation Certification Regulation*, California Environmental Protection Agency, Air Resources Board, Stationary Source Division, Project Assessment Branch. August 2007. <http://www.arb.ca.gov/regact/dg06/dg06.htm>.

## **4.2. General Observations**

Although no official sound/acoustic testing was conducted, due to other noise sources in the vicinity of the generating equipment, it was observed that the unit was quiet during operation.

The effort reported here was a measurement and verification effort, and no extended attempt was made to optimize or develop control strategies that stabilize operations. There are several areas of concern in this regard with the ENI-85 unit operation:

- The engine controls were very sensitive. Several days were required during two visits by the manufacturer's representative to tune the unit to the exacting requirements of ARB 2007. The engine controls tend to over react to slight variations in load. While the average emission levels were maintained, the spikes in emission levels occurred randomly and sporadically during operation.
- The ENI-85 power output was unstable when operated in the thermal load following mode. The unit seemed unable to stabilize the return water temperature to the engine while exerting a constant thermal load. Several changes were made to the process control PID which slightly improved the unit response to the change in the return water temperature.
- It was not possible to achieve a stable operation during the thermal load following. Not only the power output was affected by the generator unsteady operation, but also the unit emissions were unstable during thermal load following.

Where there is an assured thermal load greater than the rated electrical output of the ENI-85, it should be possible to operate the ENI-85 system within the ARB 2007 emissions guidelines. It is these applications which I-Power is seeking to serve with the ENI-85.

Using the ENI-85 to meet thermal loads that are less than the thermal output of the unit will present challenges unless further development is undertaken on the controls necessary to stabilize operation (and emissions) during thermal load changes.

## **4.3. Recommendations**

- While the ENI-85 configured for ultra-low emissions met the ARB 2007 guidelines during the short term tests, further development on unit controls is probably required to stabilize emissions at steady state during long term operation.
- Further development on unit controls to allow thermal load following while maintaining low emissions is definitely required.

## Glossary

Acronym	Definition
A	Amperes
ARB	California Air Resources Board
ASERTTI	Association of State Energy Research and Technology Transfer Institutions
BTU	British thermal units
CHP	Combined-heat-and-power
CO	Carbon monoxide
CoSPhi	Cosine of Phi
DER	Distributed energy resources
DG	Distributed generation
DUT	Device under test
EAC	Engineering Analysis Center
EPRI	Electric Power Research Institute
GM	General Motors
gpm	Gallons per minute
Hz	Hertz (Frequency)
ICE	Internal combustion engine
kVA	Kilovolt-amperes
kVAR	Kilovolt-Amperes Reactive
kW	Kilowatt
L	Liter
LHV	Lower heating value
MWh	Megawatt-Hour
NO <sub>x</sub>	Nitrogen oxides
O&M	Operation and maintenance
PID	Proportional–integral–derivative
ppm	Parts per million
psia	Pounds-force per square inch absolute
psig	Pounds per square inch gauge
QA/QC	Quality assurance / quality control

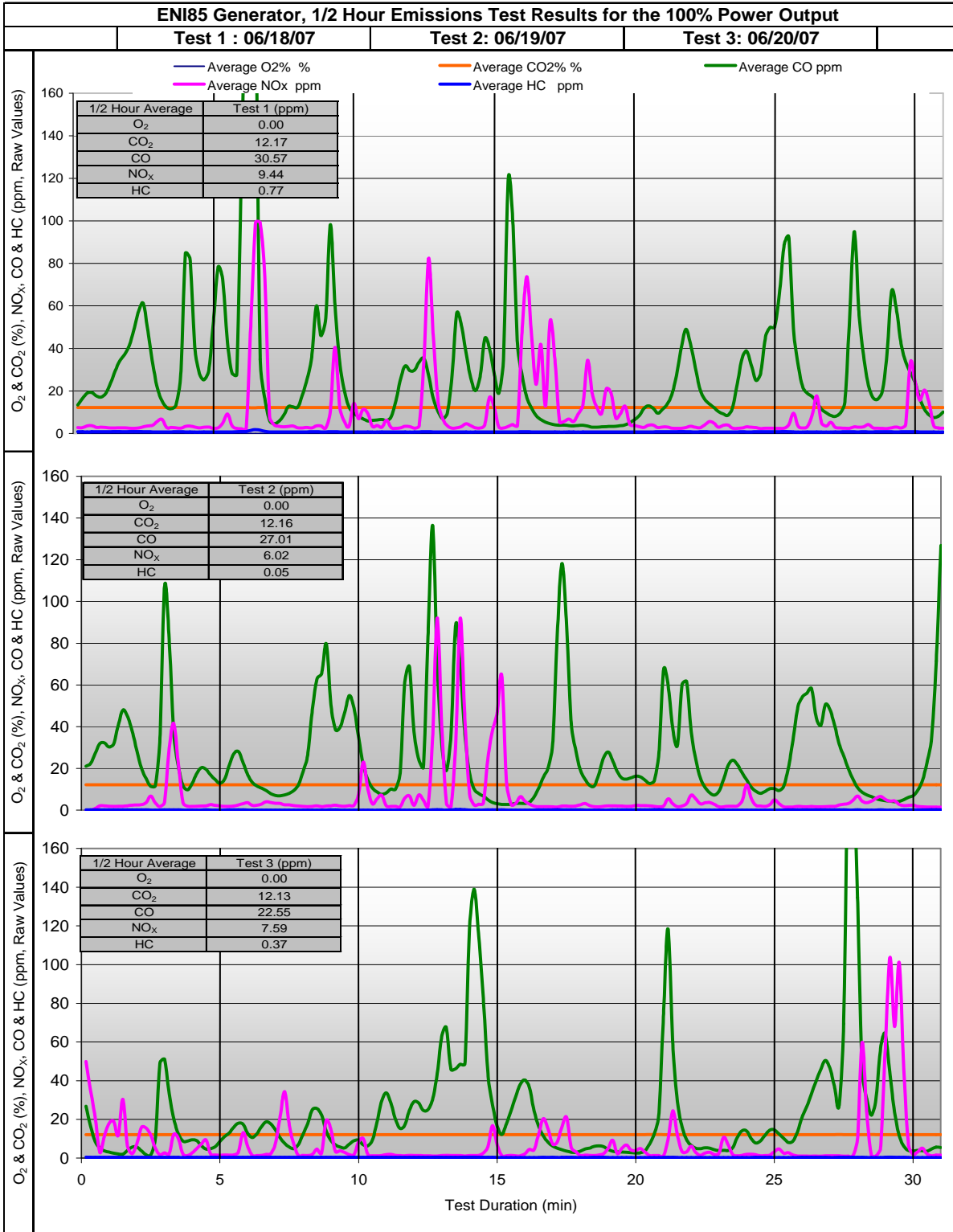
<b>Acronym</b>	<b>Definition</b>
rpm	Revolutions per minute
RTD	Resistance temperature detector
scf	Standard cubic foot
scfh	Standard cubic feet per hour
SD	Standard deviation
SoCal Gas	Southern California Gas Company
SUT	System under test
THD	Total harmonic distortion
THC	Total hydrocarbons
V	Volts
VAC	Volts (alternating current)
VOC	Volatile organic compounds

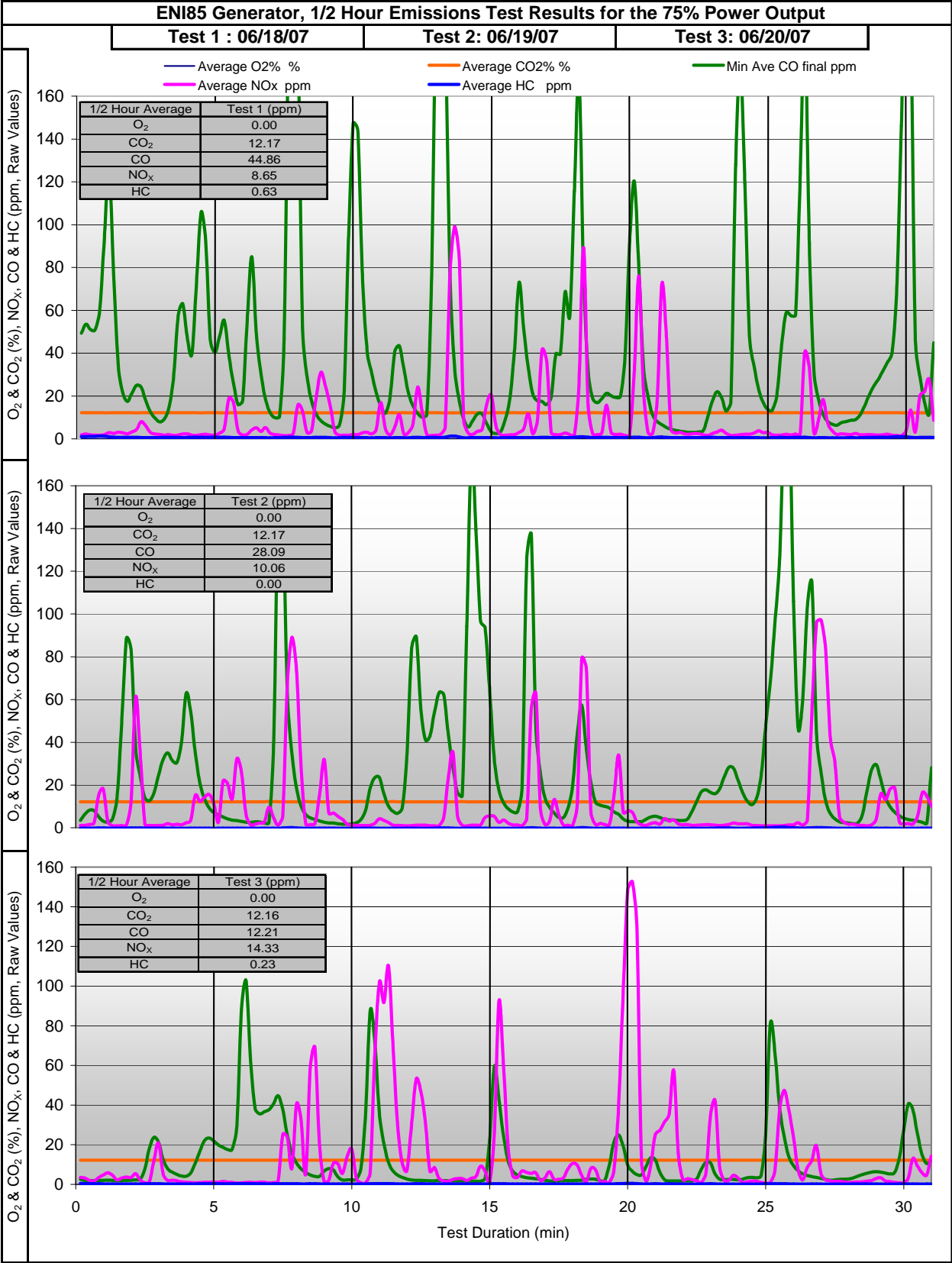
## Appendix A - Instrument Certifications

Verification Parameter	Supporting Measurement	Expected Range of Measurement	Instrument	Instrument Range	Instrument Accuracy
Electrical	Real power	0.0 – 6.0 kW	Dent Instruments ELITE <i>pro</i> multipurpose data logger	0 – 100 kW	± 1% of reading
Performance	Apparent power	0.0 – 6.3 kVA		0 – 100 kVA	± 1% of reading
	Reactive power	0.0 – 0.3 kVAR		0 – 100 kVAR	± 1% of reading
	Power factor	90 – 100%		0 – 100%	± 1% of reading
	Voltage THD	0 – 100%		0 – 100%	± 1% FS
	Current THD	0 – 100%		0 – 100%	± 1% FS
	Frequency	58 – 62 Hz		58 – 60 Hz	± 1% of reading
	Voltage	120 V		0 – 600 V	± 1% of reading
	Current	12 – 25 A		0 – 100 A	± 1% of reading
	Ambient temperature	40 – 90 °F		0 – 250 °F	± 0.4 °F
	Barometric pressure	14.5 – 15 psia	Druck Model PTX-520 pressure transducer	0 – 20 psia	± 1% of FS
	Parasitic load	200 W	Dent Instruments., ELITE <i>pro</i> data logger	0 – 100 kW	± 1% of reading
Electrical	Gas Flow	0 – 80 cfh	Dresser Roots Model 15C175	0 – 1500 cfh	± 1% of reading
Efficiency	Gas pressure	14.5 – 17.0 psia	Druck Model PTX-520 pressure transducer	0 – 20 psia	± 1% FS
	Gas temperature	40 – 80 °F	Moore Industries 4-wire RTD	0 – 250 °F	± 0.4 °F
	Gas LHV	900 – 950 Btu/scf	Daniels Model 500 gas chromatograph	0 – 2000 Btu/scf	± 0.5 Btu/1000
CHP	Transfer fluid flow	8 – 12 gpm	ABB Model C700	0 – 50 gpm	± 1% of reading
Performance	Transfer fluid supply temp.	120 – 160 °F	Moore Industries 4-wire RTD	0 – 250 °F	± 0.4 °F
	Transfer fluid return temp.	100 – 120 °F	Moore Industries 4-wire RTD	0 – 250 °F	± 0.4 °F
Emission	NO <sub>x</sub> concentration	0 – 100 ppmv	California Analytical Model 650 NO <sub>x</sub> /O <sub>2</sub> Analyzer	0 – 1000 ppmv	± 1% of range
Performance	CO concentration	0 – 300 ppmv	CAI Model ARH NDIR	0 – 1000 ppmv	± 1% of FS
	CO <sub>2</sub> concentration	0 – 10%	CAI Model ARH NDIR	0 – 20%	± 0.1% of FS
	O <sub>2</sub> concentration	8 – 15%	California Analytical Model 650 NO <sub>x</sub> /O <sub>2</sub> Analyzer	0 – 10%	± 1% of FS
	THC concentration	0 – 1000 ppmv	CAI Model 300 Flame ionization detector (FID)	0 – 3000 ppmv	± 3.0 ppmv



## Appendix B – Steady State Load Test Emissions Data



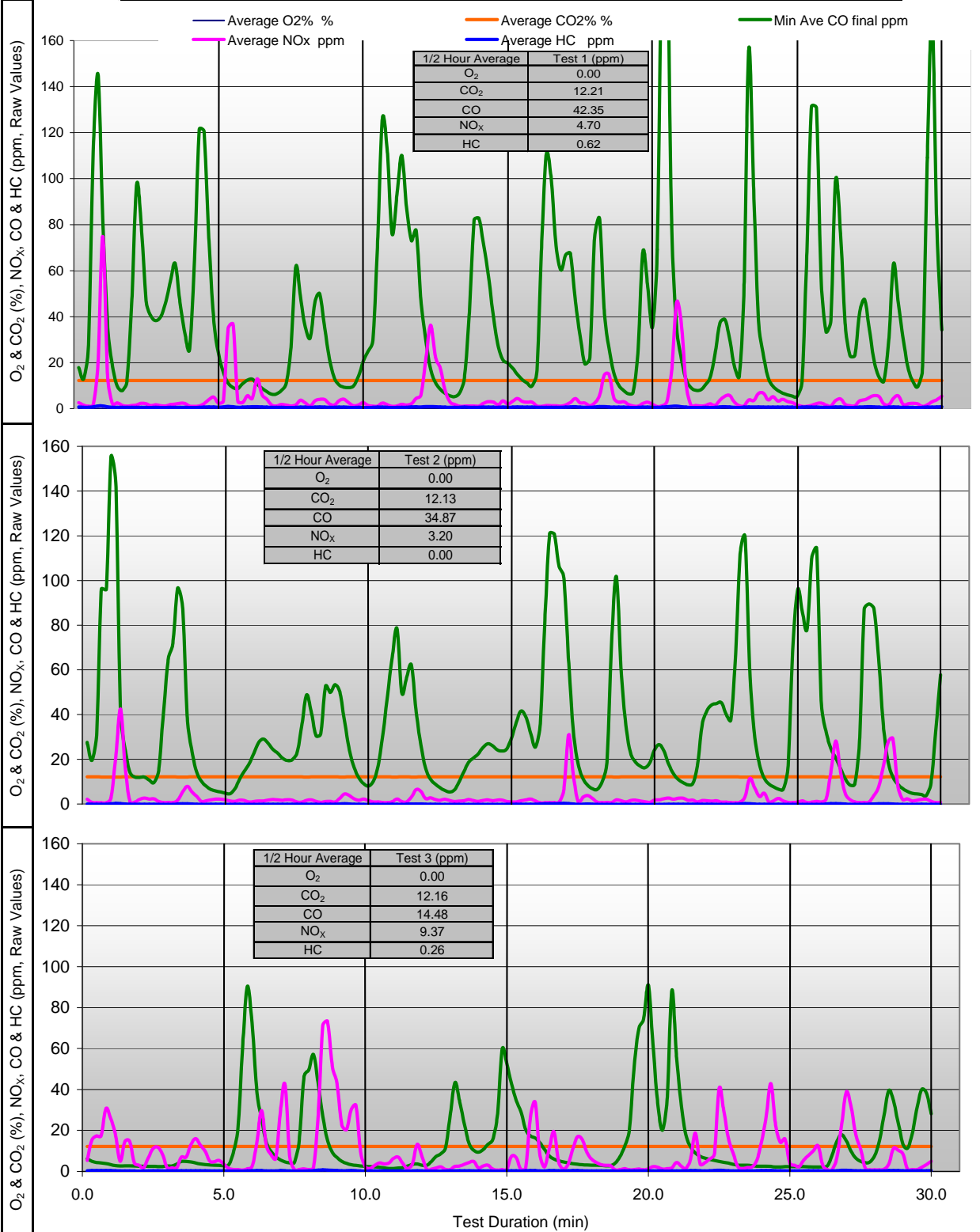


# ENI85 Generator, 1/2 Hour Emissions Test Results for the 50% Power Output

Test 1 : 06/18/07

Test 2: 06/19/07

Test 3: 06/20/07





## Appendix C - Steady State Emissions Analyzer Calibration

Zero, Span & Linearity Data							
ENI							
100% Load Test							
June 18, 2007							
	O <sub>2</sub> (%)	CO <sub>2</sub> (%)	CO Low (ppm)	CO Med (ppm)	CO Hi (ppm)	HC (ppm)	NO <sub>x</sub> Low (ppm)
<b>Analyzer Emission Ranges</b>	<b>0 - 25</b>	<b>0 - 20</b>	<b>0 - 50</b>	<b>0-100</b>	<b>0 - 500</b>	<b>0 - 1000</b>	<b>0 - 100</b>
Zero Calibration Gas	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Allowable Zero Drift (Less Than ± 3% of Range)	0.75	0.60	1.50	3.00	15.00	30.00	3.00
Zero Calibration - 08:20:35 AM	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zero Drift Check - 11:28:16 AM	0.00	0.00	0.00	-0.30	-1.77	0.00	0.00
<b>Total Drift Over Test Period</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>0.30</b>	<b>1.77</b>	<b>0.00</b>	<b>0.00</b>
<b>Was the Zero Drift Within Allowable Deviation?</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>
Span Calibration Gas	20.10	12.26	47.80	82.20	395.00	432.00	85.74
Allowable Span Drift (Less Than ± 3% of Range)	0.75	0.60	1.50	3.00	15.00	30.00	3.00
Span Calibration - 8:30:50 AM	20.10	12.30	47.80	82.80	397.20	432.70	85.80
Span Drift Check 11:16:29 - AM	20.00	12.30	47.50	81.90	392.48	437.20	86.70
<b>Total Drift Over Test Period</b>	<b>0.10</b>	<b>0.00</b>	<b>0.30</b>	<b>0.90</b>	<b>4.72</b>	<b>4.50</b>	<b>0.90</b>
<b>Was the Span Drift Within Allowable Deviation?</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>
Linearity Calibration Gas	-	-	21.97	47.40	82.20	-	45.20
Allowable Linearity Drift (Less Than ±1% of Range)	0.25	0.20	0.50	1.00	5.00	10.00	1.00
Linearity Check - 11:37:33 AM	-	-	21.70	47.70	79.80	-	45.70
<b>Difference From Mid-Range Values</b>	<b>-</b>	<b>-</b>	<b>0.27</b>	<b>0.30</b>	<b>2.40</b>	<b>-</b>	<b>0.50</b>
<b>Was the Linearity Within Allowable Deviation?</b>	<b>-</b>	<b>-</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>-</b>	<b>Yes</b>
Zero, Span & Linearity Data							
ENI							
75% Load Test							
June 18, 2007							
	O <sub>2</sub> (%)	CO <sub>2</sub> (%)	CO Low (ppm)	CO Med (ppm)	CO Hi (ppm)	HC (ppm)	NO <sub>x</sub> Low (ppm)
<b>Analyzer Emission Ranges</b>	<b>0 - 25</b>	<b>0 - 20</b>	<b>0 - 50</b>	<b>0 - 100</b>	<b>0 - 500</b>	<b>0 - 1000</b>	<b>0 - 100</b>
Zero Calibration Gas	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Allowable Zero Drift (Less Than ± 3% of Range)	0.75	0.60	1.50	3.00	15.00	30.00	3.00
Zero Calibration - 12:34:12 PM	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zero Drift Check - 01:39:24 PM	0.00	0.00	0.00	-0.20	0.00	0.00	0.00
<b>Total Drift Over Test Period</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>0.20</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>
<b>Was the Zero Drift Within Allowable Deviation?</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>
Span Calibration Gas	20.10	12.26	47.40	82.20	395.00	432.00	85.74
Allowable Span Drift (Less Than ± 3% of Range)	0.75	0.60	1.50	3.00	15.00	30.00	3.00
Span Calibration - 12:44:05 PM	20.00	12.30	45.33	80.30	397.00	431.60	85.90
Span Drift Check - 01:20:20 PM	20.00	12.30	47.59	79.25	396.09	430.90	86.00
<b>Total Drift Over Test Period</b>	<b>0.00</b>	<b>0.00</b>	<b>2.27</b>	<b>1.05</b>	<b>0.91</b>	<b>0.70</b>	<b>0.10</b>
<b>Was the Span Drift Within Allowable Deviation?</b>	<b>Yes</b>	<b>Yes</b>	<b>No</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>
Linearity Calibration Gas	-	-	21.97	47.40	82.20	-	45.20
Allowable Linearity Drift (Less Than ±1% of Range)	0.25	0.20	0.50	1.00	5.00	10.00	1.00
Linearity Check - 01:30:00 PM	-	-	21.98	46.93	79.25	-	45.50
<b>Difference From Mid-Range Values</b>	<b>-</b>	<b>-</b>	<b>0.01</b>	<b>0.47</b>	<b>2.95</b>	<b>-</b>	<b>0.30</b>
<b>Was the Linearity Within Allowable Deviation?</b>	<b>-</b>	<b>-</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>-</b>	<b>Yes</b>
Zero, Span & Linearity Data							
ENI							
50% Load Test							
June 18, 2007							
	O <sub>2</sub> (%)	CO <sub>2</sub> (%)	CO Low (ppm)	CO Med (ppm)	CO Hi (ppm)	HC (ppm)	NO <sub>x</sub> Low (ppm)
<b>Analyzer Emission Ranges</b>	<b>0 - 25</b>	<b>0 - 20</b>	<b>0 - 50</b>	<b>0-100</b>	<b>0 - 500</b>	<b>0 - 1000</b>	<b>0 - 100</b>
Zero Calibration Gas	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Allowable Zero Drift (Less Than ± 3% of Range)	0.75	0.60	1.50	3.00	15.00	30.00	3.00
Zero Calibration - 1:50:36 PM	0.00	0.00	0.00	-0.10	-0.10	0.00	0.00
Zero Drift Check - 03:03:34 PM	0.00	0.00	0.00	-0.10	-0.10	0.00	0.00
<b>Total Drift Over Test Period</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>
<b>Was the Zero Drift Within Allowable Deviation?</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>
Span Calibration Gas	20.10	12.26	47.40	82.20	395.00	432.00	85.70
Allowable Span Drift (Less Than ± 3% of Range)	0.75	0.60	1.50	3.00	15.00	30.00	3.00
Span Calibration - 2:03:44 PM	20.02	12.37	47.59	79.25	391.86	431.70	86.16
Span Drift Check - 02:43:32 PM	20.01	12.27	48.02	79.88	396.76	430.55	85.24
<b>Total Drift Over Test Period</b>	<b>0.00</b>	<b>0.09</b>	<b>0.43</b>	<b>0.63</b>	<b>4.90</b>	<b>1.15</b>	<b>0.92</b>
<b>Was the Span Drift Within Allowable Deviation?</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>
Linearity Calibration Gas	-	-	21.97	47.40	82.20	-	45.20
Allowable Linearity Drift (Less Than ±1% of Range)	0.25	0.20	0.50	1.00	5.00	10.00	1.00
Linearity Check - 02:55:12 PM	-	-	22.11	48.32	79.88	-	45.27
<b>Difference From Mid-Range Values</b>	<b>-</b>	<b>-</b>	<b>0.14</b>	<b>0.92</b>	<b>2.32</b>	<b>-</b>	<b>0.07</b>
<b>Was the Linearity Within Allowable Deviation?</b>	<b>-</b>	<b>-</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>-</b>	<b>Yes</b>

Zero, Span & Linearity Data							
ENI							
100% Load Test							
June 19, 2007							
	O <sub>2</sub> (%)	CO <sub>2</sub> (%)	CO Low (ppm)	CO Med (ppm)	CO Hi (ppm)	HC (ppm)	NO <sub>x</sub> Low (ppm)
<b>Analyzer Emission Ranges</b>	<b>0 - 25</b>	<b>0 - 20</b>	<b>0 - 50</b>	<b>0-100</b>	<b>0 - 500</b>	<b>0 - 1000</b>	<b>0 - 100</b>
Zero Calibration Gas	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Allowable Zero Drift (Less Than ± 3% of Range)	0.75	0.60	1.50	3.00	15.00	30.00	3.00
Zero Calibration - 10:21:20 AM	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zero Drift Check - 11:33:19 AM	0.00	0.00	-0.84	0.00	-0.60	-0.41	0.00
<b>Total Drift Over Test Period</b>	<b>0.00</b>	<b>0.00</b>	<b>0.84</b>	<b>0.00</b>	<b>0.60</b>	<b>0.41</b>	<b>0.00</b>
<b>Was the Zero Drift Within Allowable Deviation?</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>
Span Calibration Gas	20.10	12.26	47.40	82.20	395.00	432.00	85.74
Allowable Span Drift (Less Than ± 3% of Range)	0.75	0.60	1.50	3.00	15.00	30.00	3.00
Span Calibration - 10:27:42 AM	20.06	12.36	48.02	83.02	397.89	432.40	85.77
Span Drift Check - 11:25:39 AM	20.02	12.31	46.68	80.30	395.79	432.96	85.76
<b>Total Drift Over Test Period</b>	<b>0.04</b>	<b>0.04</b>	<b>1.34</b>	<b>2.72</b>	<b>2.10</b>	<b>0.57</b>	<b>0.01</b>
<b>Was the Span Drift Within Allowable Deviation?</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>
Linearity Calibration Gas	-	-	21.97	47.40	82.20	-	45.20
Allowable Linearity Drift (Less Than ±1% of Range)	0.25	0.20	0.50	1.00	5.00	10.00	1.00
Linearity Check - 10:38:30 AM	-	-	21.72	47.70	83.03	-	45.36
Difference From Mid-Range Values	-	-	0.25	0.30	0.83	-	0.16
<b>Was the Linearity Within Allowable Deviation?</b>	<b>-</b>	<b>-</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>-</b>	<b>Yes</b>

Zero, Span & Linearity Data							
ENI							
75% Load Test							
June 19, 2007							
	O <sub>2</sub> (%)	CO <sub>2</sub> (%)	CO Low (ppm)	CO Med (ppm)	CO Hi (ppm)	HC (ppm)	NO <sub>x</sub> Low (ppm)
<b>Analyzer Emission Ranges</b>	<b>0 - 25</b>	<b>0 - 20</b>	<b>0 - 50</b>	<b>0 - 100</b>	<b>0 - 500</b>	<b>0 - 1000</b>	<b>0 - 100</b>
Zero Calibration Gas	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Allowable Zero Drift (Less Than ± 3% of Range)	0.75	0.60	1.50	3.00	15.00	30.00	3.00
Zero Calibration - 11:34:00AM	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zero Drift Check - 1:17:28 PM	0.00	0.00	0.00	0.00	-1.56	-0.45	0.00
<b>Total Drift Over Test Period</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>1.56</b>	<b>0.45</b>	<b>0.00</b>
<b>Was the Zero Drift Within Allowable Deviation?</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>
Span Calibration Gas	20.10	12.26	47.40	82.20	395.00	432.00	85.74
Allowable Span Drift (Less Than ± 3% of Range)	0.75	0.60	1.50	3.00	15.00	30.00	3.00
Span Calibration - 11:26:00 AM	20.02	12.31	46.68	80.30	395.79	432.96	85.76
Span Drift Check - 1:09:02 PM	20.05	12.33	47.39	79.25	396.35	431.30	86.92
<b>Total Drift Over Test Period</b>	<b>0.04</b>	<b>0.02</b>	<b>0.71</b>	<b>1.05</b>	<b>0.56</b>	<b>1.67</b>	<b>1.16</b>
<b>Was the Span Drift Within Allowable Deviation?</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>
Linearity Calibration Gas	-	-	21.97	47.40	82.20	-	45.20
Allowable Linearity Drift (Less Than ±1% of Range)	0.25	0.20	0.50	1.00	5.00	10.00	1.00
Linearity Check - AM/PM	-	-	22.45	48.34	82.60	-	46.02
Difference From Mid-Range Values	-	-	0.48	0.94	0.40	-	0.82
<b>Was the Linearity Within Allowable Deviation?</b>	<b>-</b>	<b>-</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>-</b>	<b>Yes</b>

Zero, Span & Linearity Data							
ENI							
50% Load Test							
June 19, 2007							
	O <sub>2</sub> (%)	CO <sub>2</sub> (%)	CO Low (ppm)	CO Med (ppm)	CO Hi (ppm)	HC (ppm)	NO <sub>x</sub> Low (ppm)
<b>Analyzer Emission Ranges</b>	<b>0 - 25</b>	<b>0 - 20</b>	<b>0 - 50</b>	<b>0-100</b>	<b>0 - 500</b>	<b>0 - 1000</b>	<b>0 - 100</b>
Zero Calibration Gas	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Allowable Zero Drift (Less Than ± 3% of Range)	0.75	0.60	1.50	3.00	15.00	30.00	3.00
Zero Calibration - 01:29:02 PM	0.00	0.00	0.31	0.00	0.67	0.00	0.00
Zero Drift Check - 02:26:07 PM	0.00	0.00	0.46	0.42	0.81	-0.53	0.00
<b>Total Drift Over Test Period</b>	<b>0.00</b>	<b>0.00</b>	<b>0.15</b>	<b>0.42</b>	<b>0.14</b>	<b>0.53</b>	<b>0.00</b>
<b>Was the Zero Drift Within Allowable Deviation?</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>
Span Calibration Gas	20.10	12.26	47.40	82.20	395.00	432.00	85.74
Allowable Span Drift (Less Than ± 3% of Range)	0.75	0.60	1.50	3.00	15.00	30.00	3.00
Span Calibration - 1:10:00 PM	20.05	12.33	47.39	79.25	396.35	431.30	86.92
Span Drift Check - 2:07:09 PM	20.06	12.31	48.71	79.90	396.93	432.04	85.56
<b>Total Drift Over Test Period</b>	<b>0.01</b>	<b>0.02</b>	<b>1.32</b>	<b>0.65</b>	<b>0.58</b>	<b>0.74</b>	<b>1.36</b>
<b>Was the Span Drift Within Allowable Deviation?</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>
Linearity Calibration Gas	-	-	21.97	47.40	82.20	-	45.20
Allowable Linearity Drift (Less Than ±1% of Range)	0.25	0.20	0.50	1.00	5.00	10.00	1.00
Linearity Check - 2:18:00 PM	-	-	22.45	48.34	82.60	-	46.02
Difference From Mid-Range Values	-	-	0.48	0.94	0.40	-	0.82
<b>Was the Linearity Within Allowable Deviation?</b>	<b>-</b>	<b>-</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>-</b>	<b>Yes</b>

	Zero, Span & Linearity Data								
	ENI								
	100% Load Test June 20, 2007								
	O <sub>2</sub> (%)	CO <sub>2</sub> (%)	CO Low (ppm)	CO Med (ppm)	CO Hi (ppm)	HC (ppm)	NO <sub>x</sub> Low (ppm)	NO <sub>x</sub> Hi (ppm)	
Zero	Analyzer Emission Ranges	0 - 25	0 - 20	0 - 50	0-100	0 - 500	0 - 1000	0 - 100	0 - 250
	Zero Calibration Gas	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Allowable Zero Drift (Less Than ± 3% of Range)	0.75	0.60	1.50	3.00	15.00	30.00	3.00	7.50
	Zero Calibration - 08:22:02 AM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Zero Drift Check - 01:21:18 PM	0.00	0.00	-1.13	-0.92	-2.67	-0.90	0.00	-0.10
	Total Drift Over Test Period	0.00	0.00	1.13	0.92	2.67	0.90	0.00	0.10
	Was the Zero Drift Within Allowable Deviation?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Span	Span Calibration Gas	20.10	12.26	47.40	82.20	395.00	445.00	85.74	214.70
	Allowable Span Drift (Less Than ± 3% of Range)	0.75	0.60	1.50	3.00	15.00	30.00	3.00	7.50
	Span Calibration - 08:37:45 AM	20.15	12.34	47.62	82.65	397.18	445.28	85.64	207.10
	Span Drift Check - 01:01:09 PM	20.00	12.30	47.16	81.08	394.99	428.53	86.36	214.17
	Total Drift Over Test Period	0.15	0.04	0.46	1.57	2.19	16.75	0.72	7.07
	Was the Span Drift Within Allowable Deviation?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Linearity Calibration Gas	0.99	-	21.97	47.40	82.20	-	45.20	85.74
	Allowable Linearity Drift (Less Than ±1% of Range)	0.25	0.20	0.50	1.00	5.00	10.00	1.00	2.50
	Linearity Check - 08:54:42 AM	-	-	22.13	47.25	80.43	-	45.36	86.30
	Difference From Mid-Range Values	-	-	0.16	0.15	1.77	-	0.16	0.56
	Was the Linearity Within Allowable Deviation?	-	-	Yes	Yes	Yes	-	Yes	Yes
	Zero, Span & Linearity Data								
	ENI								
	75% Load Test June 20, 2007								
	O <sub>2</sub> (%)	CO <sub>2</sub> (%)	CO Low (ppm)	CO Med (ppm)	CO Hi (ppm)	HC (ppm)	NO <sub>x</sub> Low (ppm)	NO <sub>x</sub> Hi (ppm)	
Zero	Analyzer Emission Ranges	0 - 25	0 - 20	0 - 50	0 - 100	0 - 500	0 - 1000	0 - 100	0 - 250
	Zero Calibration Gas	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Allowable Zero Drift (Less Than ± 3% of Range)	0.75	0.60	1.50	3.00	15.00	30.00	3.00	7.50
	Zero Calibration - 01:21:18 PM	0.00	0.00	-1.13	-0.92	-2.67	-0.90	0.00	-0.10
	Zero Drift Check - 02:25:55 PM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Total Drift Over Test Period	0.00	0.00	1.13	0.92	2.67	0.90	0.00	0.10
	Was the Zero Drift Within Allowable Deviation?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Span	Span Calibration Gas	20.10	12.26	47.40	82.20	395.00	445.00	85.74	214.70
	Allowable Span Drift (Less Than ± 3% of Range)	0.75	0.60	1.50	3.00	15.00	30.00	3.00	7.50
	Span Calibration - 01:01:09 PM	20.00	12.30	47.16	81.30	394.99	428.53	86.36	214.17
	Span Drift Check - 02:11:00 PM	20.00	12.30	47.92	82.69	397.95	441.63	85.78	214.19
	Total Drift Over Test Period	0.00	0.00	0.77	1.39	2.96	13.10	0.58	0.02
	Was the Span Drift Within Allowable Deviation?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Linearity Calibration Gas	0.99	-	21.97	47.40	82.20	-	45.20	85.74
	Allowable Linearity Drift (Less Than ±1% of Range)	0.25	0.20	0.50	1.00	5.00	10.00	1.00	2.50
	Linearity Check - 08:54:42 AM	-	-	22.13	47.25	80.43	-	45.36	86.30
	Difference From Mid-Range Values	-	-	0.16	0.15	1.77	-	0.16	0.56
	Was the Linearity Within Allowable Deviation?	-	-	Yes	Yes	Yes	-	Yes	Yes
	Zero, Span & Linearity Data								
	ENI								
	50% Load Test June 20, 2007								
	O <sub>2</sub> (%)	CO <sub>2</sub> (%)	CO Low (ppm)	CO Med (ppm)	CO Hi (ppm)	HC (ppm)	NO <sub>x</sub> Low (ppm)	NO <sub>x</sub> Hi (ppm)	
Zero	Analyzer Emission Ranges	0 - 25	0 - 20	0 - 50	0-100	0 - 500	0 - 1000	0 - 100	0 - 250
	Zero Calibration Gas	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Allowable Zero Drift (Less Than ± 3% of Range)	0.75	0.60	1.50	3.00	15.00	30.00	3.00	7.50
	Zero Calibration - 02:25:55 PM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Zero Drift Check - 4:13:12 PM	0.00	0.00	0.47	0.38	1.10	-0.20	-0.10	-0.10
	Total Drift Over Test Period	0.00	0.00	0.47	0.38	1.10	0.20	0.10	0.10
	Was the Zero Drift Within Allowable Deviation?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Span	Span Calibration Gas	20.10	12.26	47.40	82.20	395.00	445.00	85.74	214.70
	Allowable Span Drift (Less Than ± 3% of Range)	0.75	0.60	1.50	3.00	15.00	30.00	3.00	7.50
	Span Calibration - 02:11:00 PM	20.00	12.30	47.92	82.69	397.95	441.63	85.78	214.19
	Span Drift Check - 03:40:43 PM	20.16	12.30	47.77	82.41	397.09	446.17	86.00	214.86
	Total Drift Over Test Period	0.16	0.00	0.15	0.28	0.87	4.54	0.22	0.68
	Was the Span Drift Within Allowable Deviation?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Linearity Calibration Gas	0.99	-	21.97	47.40	82.20	-	45.20	85.74
	Allowable Linearity Drift (Less Than ±1% of Range)	0.25	0.20	0.50	1.00	5.00	10.00	1.00	2.50
	Linearity Check - 2:18:00 PM	-	-	22.33	47.50	82.39	-	45.35	86.37
	Difference From Mid-Range Values	-	-	0.36	0.10	0.19	-	0.15	0.63
	Was the Linearity Within Allowable Deviation?	-	-	Yes	Yes	Yes	-	Yes	Yes



# Appendix D - Steady State VOC Analysis Reports



**AtmAA Inc.**

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## LABORATORY ANALYSIS REPORT

Speciated Hydrocarbons Analysis in Tedlar Bag Samples

Report Date: June 26, 2007  
Client: EPRI  
Site: So. Cal. Gas Co.  
Location: Pico Rivera  
Project No.: TSG6\_A109  
P.O. No.: EP501-0000024978

Date Received: June 21, 2007  
Date Analyzed: June 22, 2007

### ANALYSIS DESCRIPTION

Hydrocarbon Speciation analysis was performed by flame ionization detection/gas chromatography (FID/GC), modified EPA-18.

AtmAA Lab No.:	01727-1	01727-2	01727-3	(repeat)	01727-4	01727-5	01727-6
Sample ID:	100%	100%	75%	75%	75%	50%	50%
	T-2, S-1	T-2, S-2	T-2, S-1	T-2, S-1	T-2, S-2	T-2, S-1	T-2, S-2
	(Concentration in ppmv, component)						
Methane	1.36	1.47	1.30	1.42	1.73	1.78	1.44
non-methane hydrocarbons							
analysis by carbon							
number grouping							
	(Concentration in ppmv, as component)						
Ethene	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Ethane	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
C3	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
C4	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
C5	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
C6	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
>C6	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
TNMNE	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
TNMHC	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5

TNMNE - total non-methane, non-ethane, hydrocarbons as ppmv methane.

TNMHC - total non-methane hydrocarbons as ppmv methane.

  
Michael L. Porter  
Laboratory Director



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## LABORATORY ANALYSIS REPORT

### Speciated Hydrocarbons Analysis in Tedlar Bag Samples

Report Date: June 28, 2007  
Client: EPRI  
Site: So. Cal. Gas Co.  
Location: Pico Rivera  
Project No.: TS06\_A108  
P.O. No.: EP501-0000024978

Date Received: June 21, 2007  
Date Analyzed: June 22, 2007

### ANALYSIS DESCRIPTION

Hydrocarbon Speciation analysis was performed by flame ionization detection/gas chromatography (FID/GC), modified EPA-18.

AtmAA Lab No.:	01727-7	01727-8	01727-9	(repeat)	01727-10	01727-11	01727-12
Sample ID:	100%	100%	75%	75%	75%	50%	50%
	T-3, S-1	T-3, S-2	T-3, S-1	T-3, S-1	T-3, S-2	T-3, S-1	T-3, S-2
	(Concentration in ppmv, component)						
Methane	1.36	1.73	1.29	1.31	1.23	0.98	1.44
non-methane hydrocarbons							
analysis by carbon							
number grouping							
	(Concentration in ppmv, as component)						
Ethene	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Ethane	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
C3	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
C4	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
C5	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
C6	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
>C6	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
TNMNE	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
TNMHC	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5

TNMNE - total non-methane, non-ethane, hydrocarbons as ppmv methane.

TNMHC - total non-methane hydrocarbons as ppmv methane.

  
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Laboratory Director



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## LABORATORY ANALYSIS REPORT

Speciated Hydrocarbons Analysis in Tedlar Bag Samples

Report Date: June 26, 2007

Client: EPRI

Site: So. Cal. Gas Co.

Location: Pico Rivera

Project No.: TS06\_A109

P.O. No.: EP501-0000024978

Date Received: June 21, 2007

Date Analyzed: June 22, 2007

### ANALYSIS DESCRIPTION

Hydrocarbon Speciation analysis was performed by flame ionization detection/gas chromatography (FID/GC), modified EPA-18.

AtmAA Lab No.:	01727-13	01727-14	01727-15	(repeat)	01727-16	01727-17	01727-18
Sample ID:	100%	100%	75%	75%	75%	50%	50%
	T-4, S-1	T-4, S-2	T-4, S-1	T-4, S-1	T-4, S-2	T-4, S-1	T-4, S-2

(Concentration in ppmv, component)

Methane	1.30	1.21	0.98	0.95	0.90	1.14	0.98
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non-methane hydrocarbons

analysis by carbon


number grouping

(Concentration in ppmv, as component)

Ethene	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Ethane	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
C3	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
C4	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
C5	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
C6	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
>C6	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
TNMNE	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
TNMHC	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5

TNMNE - total non-methane, non-ethane, hydrocarbons as ppmv methane.

TNMHC - total non-methane hydrocarbons as ppmv methane.

  
Michael L. Porter  
Laboratory Director